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OF

AMERICA

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ILLUSTRATIONS

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(84 plates; 96 figures.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues a single serial octavo publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date seventeen volumes have been published and an index to the first ten volumes.

The Bulletin is sold to Fellows of the Society and to the public either in separate brochures or in complete (unbound) volumes. The *prices* are as follows: To libraries and to persons residing outside of North America, five dollars ($5.00) per volume; to persons in North America not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows); to Fellows of the Society, a variable amount, depending upon the cost of publication. These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Subscribers should specify whether they desire the brochures or the completed volume. Orders should be addressed to the Secretary, and drafts and money orders made payable to the *Secretary of the Geological Society of America*, whose address is care of the American Museum of Natural History, New York, N. Y.

Description of the Published Volumes

Volumes.	Pages.	Plates.	Figures.	Price to Fellows.
Vol. 1, 1889	593 + xii	13	51	$4.50
Vol. 2, 1890	622 + xiv	23	63	4.50
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Vol. 4, 1892	458 + xi	10	55	3.50
Vol. 5, 1893	655 + xii	21	43	4.00
Vol. 6, 1894	528 + x	27	40	4.00
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Vol. 8, 1896	446 + x	51	29	4.00
Vol. 9, 1897	460 + x	29	49	4.00
Vol. 10, 1898	534 + xii	54	83	4.00
Index to first ten volumes	209			2.25
Vol. 11, 1899	651 + xii	58	37	4.50
Vol. 12, 1900	538 + xii	45	28	4.00
Vol. 13, 1901	583 + xii	58	47	4.50
Vol. 14, 1902	609 + xii	65	43	4.50
Vol. 15, 1903	636 + x	59	16	4.50
Vol. 16, 1904	636 + xii	94	74	4.50
Vol. 17, 1905	785 + xiv	84	96	5.00

Brochures of Volume 17

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Algonkian formations of northwestern Montana. C. D. Walcott	1– 28	1–11	....	$0.80	$1.20
Recent changes of level in the Yakutat Bay region, Alaska. R. S. Tarr and L. Martin	29– 64	12–23	1– 2	.70	1.05
Carboniferous of the Appalachian basin. J. J. Stevenson	65–228	....	....	1.20	1.80
Paleogeography of Saint Peter time. C. P. Berkey	229–250	24	1– 6	.25	.35
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Cretaceous section in the Moose Mountains district, southern Alberta. D. B. Dowling	295–302	....	1	.10	.15
Crescentic gouges on glaciated surfaces. G. K. Gilbert	303–316	37–39	1–10		
Moulin work under glaciers. G. K. Gilbert	317–320	40–42	....	.60	.90
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Mohokea caldera. C. H. Hitchcock	485–496	64–66	....		
Igneous rocks of the Eastern townships of Quebec. J. A. Dresser	497–522	67–68	1	.25	.35
Lithological characters of the Virginia granites. T. L. Watson	523–540	69–72	1– 7	.30	.45
Fish remains in Ordovician rocks in Bighorn mountains, Wyoming, with a résumé of Ordivician geology of the Northwest. N. H. Darton	541–566	73–79	1– 6	.50	.75
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Proceedings of the Eighteenth Annual Meeting, held at Ottawa, Canada, December 27, 28, and 29, 1905, including proceedings of the Seventh Annual Meeting of the Cordilleran Section, held at Berkeley, California, December 29 and 30, 1905. H. L. Fairchild, *Secretary*	671–785	80–84	4	1.60	2.40

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 17 have been issued:

Editions uniform with the Brochures of the Society

Pages	1– 28,	plates 1–11;	100 copies.		May	17, 1906.
"	29– 64,	" 12–23;	330 "	*	"	25, 1906.
"	65–228,		280 "		"	28, 1906.
"	229–250,	plate 24;	280 "		June	8, 1906.
"	251–274,	plates 25–31;	200 "		"	22, 1906.
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"	451–468,	" 55–58;	200 "		September	24, 1906.
"	469–484,	" 59–63;	180 "		October	18, 1906.
"	485–496,	" 64–66;	180 "		"	18, 1906.
"	497–522,	" 67–68;	130 "		"	18, 1906.
"	523–540,	" 69–72;	30 "		December	31, 1906.
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Pages	673–679, §	30 copies.		March	30, 1907.
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* 250 copies with pagination at bottom.

† 130 with covers, 200 without covers.

‡ Bearing the imprint [From Bull. Geol. Soc. Am., Vol. 17, 1905.]

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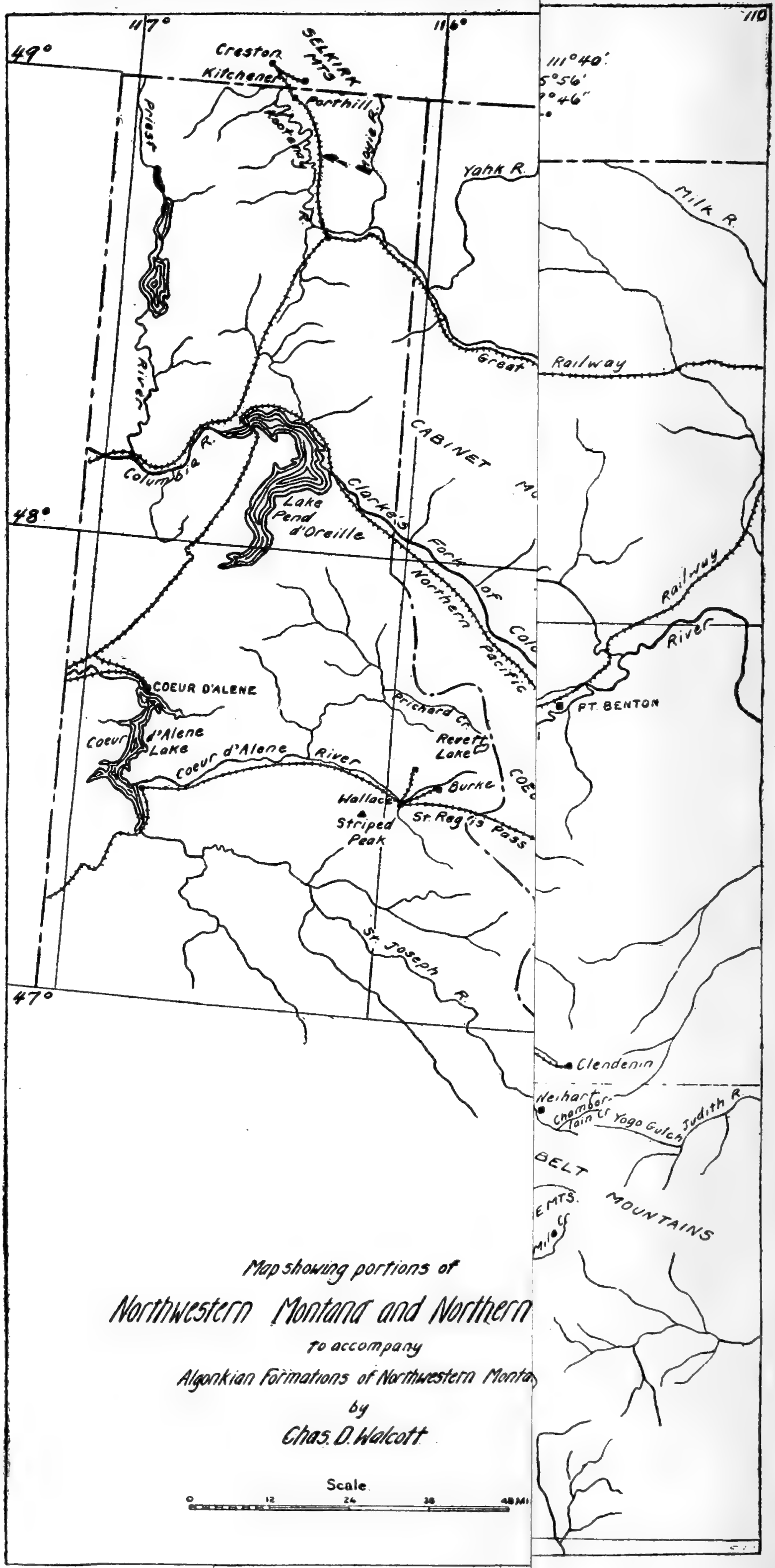
CORRECTIONS AND INSERTIONS

All contributors to volume 17 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 15, remarks column; *for* "thickness eastward" *read* thickens eastward
Plate 16, figure 1; *for* "forest" read foreset
" 23, *add* the following: + means uplift, — means depression
Page 60, line 7 from bottom; *for* "see fault line" *read* see unlettered fault line
" 61, line 5 from top; *omit* "unlettered"
" 279, line 4 from top; *for* "probably" *read* possibly
" 279, line 19 from bottom; *for* "Toqueville" *read* Toquerville
" 279, footnote; *for* "Toqueville" *read* Toquerville
" 281, line 18 from bottom; *after* "Detrital-Sacramento" *add* valley
" 282, line 13 from bottom; *for* "Gravel canyon" *read* Grand canyon
" 488, line 2 from top; *for* "figure" *read* plate 64
" 505, line 21 from top; *before* "however" *insert* not
" 505, line 15 from bottom; *for* "bolt" *read* belt
" 519, lines 7 and 8 from bottom; *for* "Nordmarkase" *read* Nordmarkosi
" 522, line 15 from top; *for* "inclusive" read intrusive
" 637, line 24 from top; *for* "1906" *read* 1905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Yogo Gulch
Judith R.
BELT MOUNTAINS
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Map showing portions of
Northwestern Montana and Northern
to accompany
Algonkian Formations of Northwestern Monta
by
Chas. D. Walcott
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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 17, PP. 1-28, PLS. 1-11 MAY 17, 1906

ALGONKIAN FORMATIONS OF NORTHWESTERN MONTANA

BY CHARLES D. WALCOTT

(Presented by title before the Society December 29, 1905)

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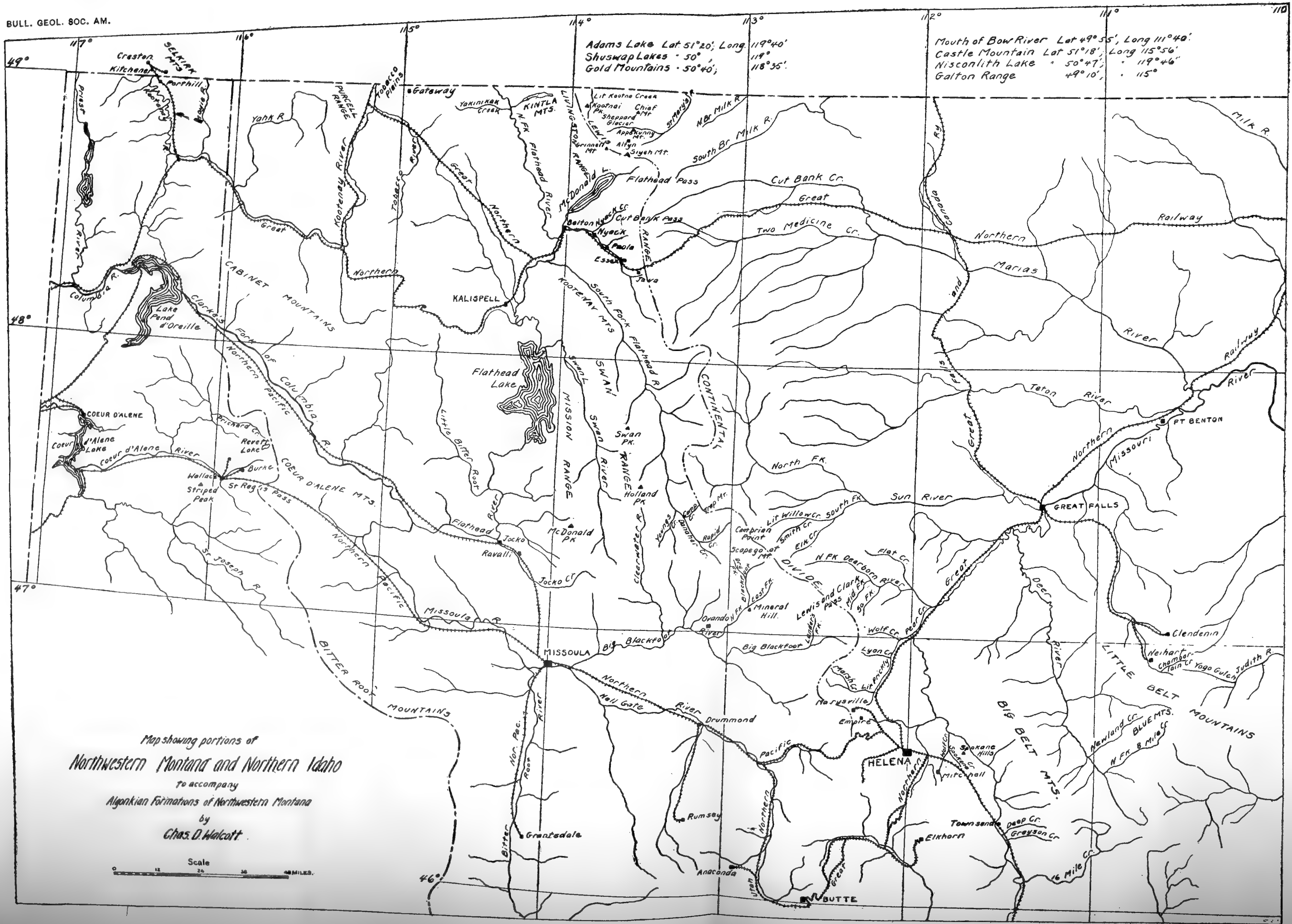


MAP OF PORTIONS OF NORTHWESTERN MONTANA AND NORTHERN IDAHO

Introduction

In 1898 I made a reconnaissance of the pre-Cambrian formations of the Belt mountains of Montana and published the results.* The section extended from the unconformable Cambrian above to Archean complex at the base. In 1900 I crossed the Belt mountains and endeavored to trace the connection, north of Helena, of the Belt terrane and the pre-Cambrian rocks of the Rocky Mountain "front" at Lewis and Clark pass and north on the south fork of the Dearborn river. It was evident that a great series of strata extended westward beneath the Cambrian that was in general similar to the Belt terrane, but quite different in detail. In 1901, at my request, Mr Bailey Willis studied the Front ranges of the Rocky mountains in northern Montana and found a great series of strata referred to the Algonkian.† In the survey of the Cœur d'Alene mining district of Idaho Mr F. L. Ransome, assisted by Mr F. C. Calkins, found most of the region underlain by stratified, siliceous rocks, referred to the Algonkian.‡ During the field season of 1905 Mr Calkins continued the study of the Algonkian rocks of Idaho, and extended his examinations into western Montana, nearly to Ravalli, on the Northern Pacific railroad. I also had the opportunity of studying the pre-Cambrian rocks of northwestern Montana in 1905, and of measuring the section from northwest of Scapegoat mountain on the Continental divide, westward, crossing the Swan and Mission ranges, to the canyon of Jocko creek above Ravalli.

In this paper I wish to compare the various sections thus far studied and to correlate them as far as practicable. The Camp Creek, Mission Range section will be taken as the type section, owing to its being capped by Cambrian strata and being of greater vertical range than any other known section. It embraces portions of the northern section of Mr Willis and the western section in the Cœur d'Alene district.

Stratigraphic Sections

CAMP CREEK, MISSION RANGE SECTION

The section in general.—The upper portion of Scapegoat mountain, in the southeastern portion of the Lewis and Clark forest reserve, is formed

* Bull. Geol. Soc. Am., vol. 10, pp. 201-215, 235-239.

† Bull. Geol. Soc. Am., vol. 13, pp. 314-324.

‡ Manuscript of Geologic Folio, U. S. Geological Survey.

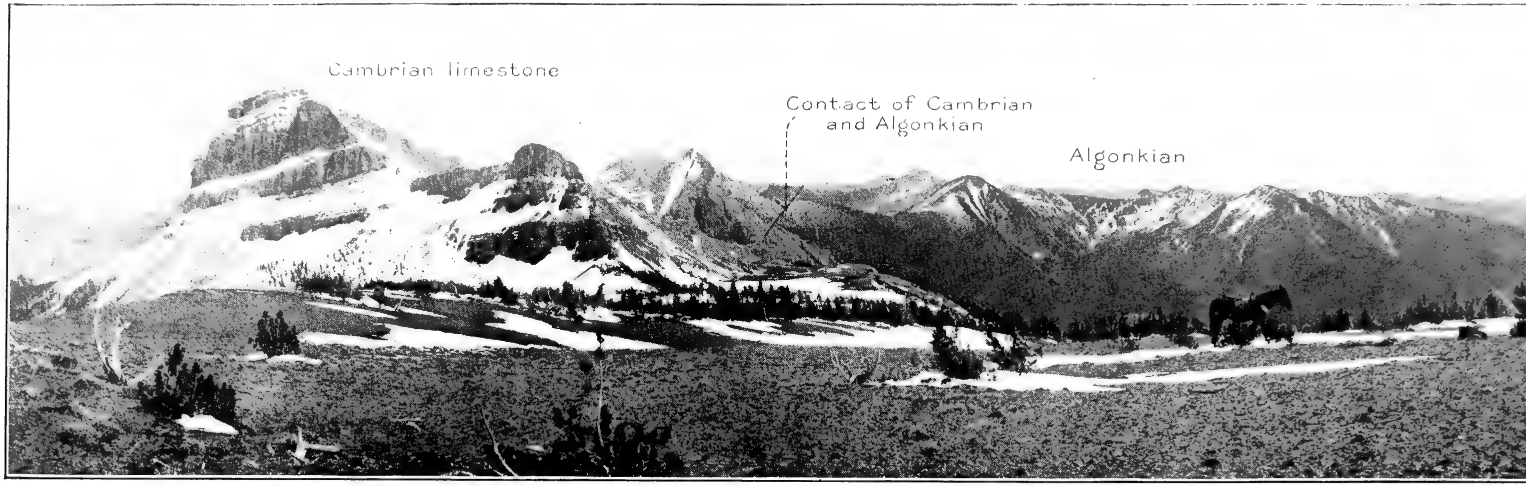


FIGURE 1.—NORTHWEST END OF SCAPEGOAT MOUNTAIN FROM CONTINENTAL DIVIDE ON THE NORTH

Upper portion of mountain is Cambrian. Camp Creek series extends from beneath limestone to southwest (to right) toward north fork of Blackfoot river. C. D. W., 1905

FIGURE 2.—RIDGE ON WEST SIDE OF CAMP CREEK SHOWING UPPER PORTION OF SECTION OF ALGONKIAN ROCKS BENEATH THE CAMBRIAN

Point in foreground is on Continental divide 4 miles north of Scapegoat mountain, Ovando quadrangle, Montana. C. D. W., 1905

SCAPEGOAT MOUNTAIN AND RIDGE ON WEST SIDE OF CAMP CREEK

of a great mass of Cambrian limestone, extending 6 miles on a northwest-southeast axis and varying in width from one to two miles (see plate 2, figure 1). The southeast point is Scapegoat (9,185 feet elevation) and the northwest elevation (9,000 feet) I shall call Cambria. The limestones are superjacent to siliceous Algonkian strata forming the main ridge of the Continental divide and the spurs descending from it on the north, west, south, and southeast. On the east and northeast the Cambrian limestones slope toward the Dearborn River drainage.

After a reconnaissance of the area I decided to measure the Algonkian section at localities where each of its units, or formations, were well exposed and in contact above and below with other known formations.

For the first, or upper, series of strata the sharp ridges on the southeast and northwest sides of Camp creek were selected (see plate 2, figure 2). Camp creek heads close to the Continental divide, northwest of Trap mountain, and 12 miles northwest of Cambrian point. It flows south-southwest to where it enters Danaher creek, 4 miles above the head of the south fork of the Flathead river.*

Cambrian, Flathead sandstones.—The massive, coarse grained sandstones of the Flathead series overlie the Algonkian strata of the Camp Creek, Mission Range section at the summit of the Continental divide.

The fine conglomerate at the base of the Flathead sandstone of the Middle Cambrian rests in apparent conformity on the Algonkian strata, the layers of both formations dipping north at an angle of 70 degrees.

Algonkian, Belt terrane.—The Algonkian strata of the Camp Creek, Mission Range section, comprise three great series, the Camp Creek, the Blackfoot, and the Ravalli, as follows:

Camp Creek series

	Feet	Feet
1*a*. Compact, hard, gray sandstones, almost quartzitic in many layers; layers vary in thickness from one-fourth inch to 10 inches; often marked by mud cracks and ripples; toward the top the dip is about 70 degrees north; 500 feet in thickness below, the dip increases to 80 degrees, and decreases to 75 degrees near the base....	1,762†	1,762
From this point the section was measured on the east side of Camp creek.		
2*a*. Reddish brown, arenaceous shales and thin bedded limestones, alternating irregularly with greenish gray bands of shales and sandstones. Some of the thicker layers, 2 to 6 inches, are almost quartzitic...........	1,560	1,560

* See topographic map of Ovando quadrangle, Montana.

† All thicknesses, unless otherwise stated, were obtained by measuring the strata with rod and clinometer, a method that gives reliable results. (See Proc. U. S. Nat. Museum, 1888, vol. xi, p. 447.)

	Feet	Feet
3*a*. Greenish, sandy shales, with thin layers of greenish gray, compact sandstone at irregular intervals............	612	
b. Reddish brown, shaly sandstones......................	51	
c. Reddish brown, thin bedded sandstones, becoming more massive, compact, and almost quartzitic 50 to 75 feet down. About 50 feet from the base the layers are more or less cross-bedded, coarser grained, reddish gray in color, and from 2 to 14 inches in thickness....	970	
d. Reddish brown sandstones that, 285 feet from the top, gradually pass into alternating thin bedded, reddish colored, sandy shales and sandstones. Toward the base there is 60 feet of reddish and green, sandy shales	1,362	
e. Reddish brown, thin bedded and shaly sandstones. Ripple markings and mud cracks occur abundantly in upper part	76	
f. Grayish red sandstone in layers 8 inches to 2 feet thick, alternating with shaly sandstone bands and partings..	510	
g. Reddish brown sandstones and shaly beds.............	910	
		4,491
4. Alternating thin bedded, gray, hard sandstones and sandy shales, alternating with an occasional quartzitic sandstone; layers 8 to 12 inches thick. At 360 feet down light gray, sandy shales, slightly calcareous in places, have a thickness of about 30 feet. Below, the sandstone layers are thicker, with less shaly beds, and almost quartzitic in the thicker layers. At 175 feet from the top a reddish brown belt 15 feet thick occurs; otherwise this great gray sandstone band and a similar band below (6*c*) are conspicuous features in the ridges, as the gray color is in strong contrast with the rich, reddish brown bands. Ripple marks and mud cracks are of frequent occurrence...........	700	700
5. Compact, impure, gray limestone, siliceous, arenaceous, thin bedded, and shaly, weathering buff to yellow on many of its layers...............................	198	198
6*a*. Gray sandstones in layers 2 to 8 inches thick, with alternating bands and parting of shaly sandstones.........	482	
b. Reddish brown, thin bedded, and shaly sandstones......	68	
Sixteen feet from the top a layer about 15 inches thick is nearly made up of irregularly semispherical masses of Cryptozoan. The latter are calcareous in an impure sandstone matrix.		
c. Gray, shaly, and thin bedded, compact sandstone........	425	
		975

A bed of Cryptozoan occurs 325 feet below the summit, in a rough, gray sandstone layer about 4 feet thick.

	Feet	Feet
7*a*. Reddish brown sandstones, thin bedded and often shaly..	753	
b. Gray, thin bedded, and almost shaly sandstones, with mud cracks and ripple marks..........................	158	
c. Reddish brown, thin bedded, and often shaly sandstones..	623	
d. Gray, thin bedded, and shaly sandstones, with mud cracks, wave and ripple markings..........................	85	
e. Chocolate red, thin bedded sandstones, alternating with impure, gray, arenaceous limestone layers...........	395	
		2,014

Cryptozoan is abundant in small forms in a layer 6 inches thick, 25 feet from the top.

Résumé

	Feet	Feet
1. Gray sandstones	1,762	1,762
2*a*. Reddish sandstones....................................	1,560	1,560
3*a*. Greenish sandstones and shales......................	612	
c-d. Reddish brown sandstones..........................	2,332	
e-g. Reddish sandstones................................	1,496	
		4,491
4. Gray sandstone	700	700
5. Siliceous limestone	198	198
6*a*. Gray sandstone	482	
b. Reddish sandstone....................................	68	
c. Gray sandstone....................................	425	
		975
7*a*. Reddish sandstone	753	
b. Gray sandstone	158	
c. Reddish sandstone	623	
d. Gray sandstone	85	
e. Reddish sandstone	395	
		2,014
Total of Camp Creek series..............................		11,700

Blackfoot series

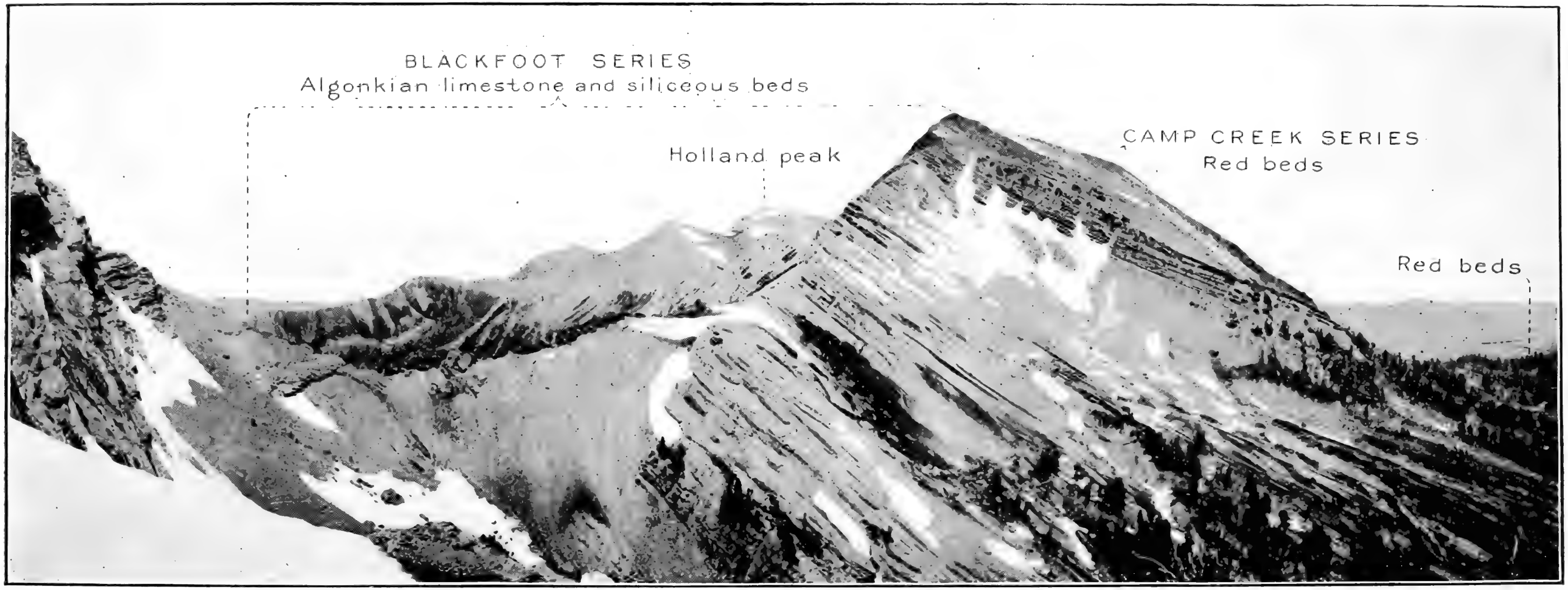
Type locality of Blackfoot series: Canyon of North fork of Blackfoot river, where the entire section is exposed.

The red beds of the Camp Creek series rest conformably on the limestones of the Blackfoot series, about a mile above the mouth of Camp creek. The contact between the two formations can be traced for many miles to the north, south, and southeast. At Camp creek the Blackfoot limestones are broken by a fault in the canyon valley of Danaher creek, but to the south, 10 miles west of south of Scapegoat mountain, the entire section of the limestone is shown conformably beneath the Camp Creek terrane in fine exposures in the canyon of the north fork of Blackfoot

river, below Dry fork. The section was measured on the high ridge east of the river, and passes over Mineral hill.

Above the Blackfoot limestones the red and gray arenaceous beds of the Camp Creek series extend northward and pass beneath the Cambrian strata of Scapegoat mountain.

	Feet	Feet
1. Passage bends; sandy layers, pinkish to dull red, with coarser grains of sand than below, followed by grayish, buff weathering, slightly calcareous, fine grained sandstones. The upper half has more buff and yellowish beds and the lower half more of the reddish beds......	155	
2. Shaly limestones, alternating with thin layers of gray limestone. Near the top a few oolitic layers occur, and throughout are occasional layers with Cryptozoan. About 730 feet down the shaly beds give way to bedded, gray limestone, alternating with impure, dark gray, buff weathering limestone. About 160 feet from the base the shaly limestone again predominates, with frequent layers of oolitic and siliceous limestone......	1,310	
Cryptozoan is abundant in the lower 100 feet.		
3. Calcareous shales with bands of green arenaceous shale...	155	
4. Thin bedded and shaly, gray limestone, with occasional layers of gray limestone 2 to 10 inches thick. In the lower 70 feet, oolitic layers and semi-cherty layers occur. The siliceous portions of the latter weather buff and the irregular nodules and stringers of gray limestone a bluish gray	815	
Cryptozoan occurs abundantly in the upper 60 feet on the high point north-northeast of Mineral hill. Fine specimens of Cryptozoan two feet and more in diameter occur in beds 3 feet thick at horizons 360 and 373 feet below the top.		
5. Thin bedded, more or less shaly, compact, gray limestone, weathering buff and gray...........................	520	
6. Gray limestone in layers 8 to 20 inches thick, with irregular nodules and stringers of cherty matter, weathering buff. This extends down about 330 feet, where there is a gradual change into banded calcareous and siliceous beds, with layers of gray limestone. These give way 1,040 feet down to gray, compact, siliceous, buff weathering limestone in shaly bands and thin layers. Siliceous matter becomes more prominent, until the only evidence of calcareous matter is the buff weathering beds. A bed 28 feet thick of purplish colored, siliceous rock, in hard, compact, smooth layers, occurs 285 feet above the base...........................	1,850	
Cryptozoan of large size, 15 inches and more in diameter, occur 165 feet from the top.		



HOLLAND PEAK, SWAN RANGE, MONTANA

View from south. Summit of ridge is Blackfoot Algonkian limestone, with basal beds of the red sandstones of the Camp Creek series on eastern slope (right of picture). C. D. W., 1905

SOUTHEASTERN SLOPE OF MOUNT McDONALD, MISSION RANGE, MONTANA

The strata forming Mount McDonald are the calcareous and siliceous beds of the Blackfoot series. C. D. W., 1900

CREST OF MISSION RANGE, MONTANA

This view, taken a short distance south of Mount McDonald, shows the effect of glacial erosion on the slightly altered calcareous and siliceous beds of the Blackfoot series. C. D. W., 1900

Résumé

	Feet	Feet
1. Calcareo-arenaceous beds	155	
2. Shaly limestones	1,310	
3. Calcareo-arenaceous shales	155	
4. Thin bedded limestone	815	
5. Shaly and thin bedded limestone	520	
6. Siliceous limestone	1,850	
		4,805

In this section, below the Blackfoot series, the purple and green siliceous beds of the Ravalli series have a thickness of 2,150 feet to a fault 2.5 miles south of Mineral hill.

Ravalli series

The Blackfoot Limestone series, with the siliceous red beds above and purple beds below, are repeated to the westward of the Continental divide, in the Swan and Mission ranges, the limestones forming the high summits on both ranges (see plate 3). West of the Mission range the lower portion of the Blackfoot series is exposed in the high hills east of Ravalli and Jocko creek. Below the limestones there is a great thickness of siliceous strata, the lowest beds of which were found on Jocko creek, about a mile above Ravalli.

	Feet	Feet
1. Fine grained, quartzitic sandstones of purplish gray and gray color. In the lower portion the purple to purplish gray form bands of color, and above the gray and then the purplish tints predominate	2,550	
2. Bedded, compact, gray sandstones	1,060	
3. Greenish gray, fine grained, compact, quartzitic sandstones, in layers 4 inches to 2 feet thick, with an occasional bed of shaly sandstone	4,645	

Résumé

1. Purple and gray beds	2,550	
2. Gray beds	1,060	
3. Greenish gray beds	4,645	
		8,255

Résumé of Camp Creek, Mission Range section.—The following is a résumé of the Camp Creek, Mission Range section:

Cambrian.
Plane of unconformity.
Algonkian, Belt terrane.

Camp Creek series	11,700	
Blackfoot series	4,805	
Ravalli series	8,255	
		24,760

DEARBORN RIVER SECTION

Location of the section.—This section is on the south side of the ridge south of the north fork of Dearborn river and 35 miles southeast of the Camp Creek section. It is 10 miles north of the Lewis and Clark pass.

The section begins about 2 miles up the slope below the base of the Flathead Cambrian sandstone, and extends eastward to the gravels at the foot of the mountain slope, a short distance west of the ranch house of Steinbach and Alt.

Cambrian, Flathead sandstones.—The Cambrian Flathead sandstone is massive, coarse grained, with small, white quartz pebbles, and cross-bedded near base. Two hundred and fifty-five feet from the base it is overlain by thin bedded sandstones and shales, with numerous annelid trails and fragments of trilobites. The Flathead sandstone rests unconformably upon the Algonkian (see page 16).

Algonkian, Belt terrane.—The following is the Algonkian section exposed on the north fork of the Dearborn river:

	Feet	Feet
1*a*. Gray, buff weathering, arenaceous, thin bedded layers, passing into greenish gray beds 65 feet from the top...	225	
b. Cryptozoan, siliceous limestone........................	4	
c. Thin bedded, hard, gray sandstone weathering buff and gray, with greenish tints..........................	205	
d. Buff colored, arenaceous shale........................	76	
		510
2. Buff weathering, gray, slightly siliceous limestone in shales and layers up to a foot in thickness. Massive layers of interformational conglomerate, composed of broken up, shaly, and thin bedded, bluish gray limestone, occur 180 feet from the top and bluish gray layers extend below for 25 feet. Oolitic layers occur at several horizons	435	
3*a*. Greenish, arenaceous shales, with thin, interbedded sandstones at irregular intervals. At about 500 feet from the top alternating bands of greenish and purplish, arenaceous shale begin, and continue for some distance before giving way to purple colored, siliceous layers, and thin bedded, fine grained sandstone and purple shales	1,150	

Strike of strata near base, north 40 degrees west, magnetic; dip 25 degrees southwest, near. About 1,000 feet from base, same strike, dip 30 degrees southwest.

	Feet	Feet
b. Light gray and greenish, siliceous beds in layers and shaly bands. Alternating bands of arenaceous, shaly, and thin bedded sandstones and compact, siliceous, banded layers, flint-like in appearance, occur throughout this part of the series. At 455 feet from the top a sill of dark, eruptive rock, 35 feet thick, outcrops, and 17 feet above, 3 feet of dark, siliceous, hard shale. Mud cracks occur at many horizons..................	1,215	
c. Purple, arenaceous shales with occasional thin bands of greenish shale. In the upper part the greenish shales predominate, with occasional bands of purple shales... Dip 45 degrees southwest.	2,430	
d. Fine, quartz conglomerate............................	2	
e. Shaly and thin bedded, siliceous and arenaceous shales. They are purple colored in the upper 245 feet and with occasional purple bands in greenish shales below. At 300 feet from the top a bed of eruptive rock 25 feet thick occurs and another 5 feet thick 435 feet below. Dip 30 degrees near base and 40 degrees near top of 3*e*.		
4. Bluish gray limestone in thin layers....................	15	

Résumé

1*a-d*. Gray and greenish gray, siliceous and arenaceous beds..	510	
2. Gray, siliceous limestone...............................	435	
3*a-e*. Greenish and purple, siliceous and arenaceous beds.....	5,757	
4. Gray limestone	15	
		6,717

The upper portion of this section, 1*a-d* and 2, appears to belong to the Blackfoot Limestone series, and the beds below to the Ravalli series of the Camp Creek, Mission Range section.

The Cambrian beds are cut off by a fault just above the Flathead sandstones, which brings up gray, arenaceous shales and sandstones of the Algonkian, and above these, brownish red beds corresponding to the Spokane shales of the Lewis and Clark Pass section. The latter are capped by the coarse sandstone of the Cambrian Flathead formation.

LEWIS AND CLARK PASS SECTION

Location of the section.—This section is about 10 miles south of that south of the north fork of the Dearborn river.

Cambrian, Flathead sandstones.—The divide at the Lewis and Clark pass trends northeast and southwest. The massive bedded, coarse sand-

stones of the Cambrian Flathead formation form the northwest side and the reddish brown sandstones and shales of the Algonkian Belt terrane the southeastern side, the Algonkian lying unconformably below the Cambrian.

Algonkian, Belt terrane.—The Algonkian at the Lewis and Clark pass comprises the Marsh, the Helena, and the Empire formations, as follows:

Marsh formation

	Feet	Feet
1. Reddish brown, arenaceous shales and sandstones, similar to the Marsh shales of the Belt terrane................	790	
2. Gray, hard, arenaceous shales and sandstones, with alternating bands of reddish brown, thin bedded and shaly sandstones, 20 to 40 feet in thickness................	225	

Helena formation

Thin bedded, gray, siliceous limestone, with numerous arenaceous layers in the upper 25 feet. The central and lower portions have interbedded, bluish gray limestone with occasional layers of interformational conglomerate, formed of thin, shaly limestones. The siliceous, hard layers weather a yellowish buff color...........	285	

Empire formation

Gray, arenaceous shales and thin bedded sandstones. A bed of Cryptozoan limestone two feet thick occurs near the top and a similar bed 360 feet below.................	1,210	

Résumé of Algonkian, Belt terrane

Marsh formation:		
1. Reddish brown, arenaceous shales and sandstones.........	790	
2. Gray, arenaceous shales and sandstones..................	225	
Helena formation:		
Gray siliceous limestones	285	
Empire formation:		
Gray, arenaceous shales and sandstones....................	1,210	
Total section		2,510

SWAN RANGE SECTION

Location of the section.—The section of the limestones and interbedded siliceous strata of the Swan range, south of Holland peak, begins beneath the red sandstones of the Camp Creek series and extends westward, over the crest of the range, nearly to its western base.

Algonkian.—The red and gray arenaceous beds of the Camp Creek series form the top of the Algonkian section in the Swan range, and overlie the limestones of the Blackfoot series.

Blackfoot series—Upper division

	Feet	Feet
1*a*. Banded, siliceous or cherty layers predominate at the top, with a few thin layers of gray limestone and shaly, arenaceous layers 6 to 15 inches thick	410	
b. Gray, thin bedded limestones, with intercalated cherty layers	585	
		995
2*a*. Gray, banded chert, with a dark bluish black layer 2 feet thick near the top	23	
b. Gray, thin bedded limestone, weathering buff, somewhat shaly in the upper 600 feet and more distinctly bedded below	845	
c. Alternating cherty beds and grayish limestone, with the cherty beds predominating in the upper portion	195	
Near the base there is a layer three feet in thickness almost entirely made up of massive specimens of Cryptozoan.		
d. Gray, thin bedded cherty beds	52	
e. Gray, rough, siliceous, and arenaceous limestone in thick layers	109	
f. Dark, bluish black cherty bed	4	
g. Gray, rough, siliceous, and arenaceous limestone layers 2 to 16 inches thick	105	
About 50 feet from the summit numerous specimens of Cryptozoan occur in a bed about 6 inches in thickness.		
Total of Upper division		2,328

Blackfoot series—Lower division

	Feet
1*a*. Banded cherts, dark and gray	70
b. Gray, compact, more or less siliceous limestone, with cherty layers and irregular nodules that correspond in form to the calcareous nodules in 1*f*	80
c. Dark and gray banded cherts	65
d. Gray, compact, more or less siliceous limestone, with thin cherty layers and irregular nodules similar to the cherty matter in 1*f*	175
e. Banded, cherty beds, with small amount of calcareous matter in the form of nodules and irregular thin layers	210
f. Siliceous and calcareous layers, from one-half to 2 inches in thickness. The calcareous matter is in the form of	

	Feet	Feet
irregular, bluish gray, limestone nodules, imbedded in a siliceous matrix. Sometimes the siliceous matter, and sometimes the calcareous, predominates, and occasionally layers that are purely siliceous, or arenaceous limestone, occur, and banded, cherty layers are of frequent occurrence. Occasionally the nodules of limestone are small, very irregular in size and form, and almost make up the entire mass of the rock, the siliceous matter simply holding them together..........	960	
g. Light gray, cherty, siliceous, banded beds, 1 to 2 feet in thickness, with partings of siliceous shale at irregular intervals. Layers occur with numerous flattened bluish gray, limestone nodules and stringers arranged parallel to the bedding. Some of the shaly beds are 1 to 2 feet in thickness and more or less argillaceous or calcareous. On the weathered surface the calcareous beds weather buff and dull gray. Seventy feet below the top there is a band of arenaceous, gray shale 35 feet in thickness...	1,100	
The section was all carefully measured, with the exception of the lower 600 feet, which was estimated from dip and occasional outcrops on the lower slopes of the ridge.		
Total of Lower division..............................		2,660
Total thickness		4,988

The Upper division contains more calcareous matter, and the Lower division is more siliceous. The separation is somewhat arbitrary, and probably would not hold good at any considerable distance from where the section was measured.

The general strike of the beds of the section is north 30 degrees west; average dip, 35 degrees north.

NOTES ON SECTION FROM BELTON, EAST

Bad Rocks Canyon section.—During September, 1895, I made a rapid trip along the line of the Great Northern Railroad track from Belton to the vicinity of Essex, and thence north to the head of Nyack creek.

In Bad Rocks canyon, Montana, on the line of the Great Northern railroad, the section given below was measured. This portion of the section appears to correspond with the Blackfoot limestone of the Mission Range section, 85 miles to the south, and to indicate that that horizon is persistent on the line of the strike of the Mission and Swan ranges. The section is as follows:

Descending series.	Feet
1. Banded blue and gray arenaceous limestone	700
2. Dark bluish limestone in massive beds	650
3. Greenish colored limestone, impure and with many small calcareous nodules	1,600
4. Dark bluish limestone (similar to number 2)	250
5. Greenish, banded, massive argillaceous limestone	2,000
6. Alternating green and purple argillaceous beds, massive layers passing (at about 100 feet) into sea green	450
6*a*. Green, passing down into purple (same as number 6)	350
	6,000

No fossils; no well defined base or summit.

In the notes taken at the time the following occur:

At Belton greenish shales and massive beds of calcareous argillite-like rock dip northerly about 40 degrees. Bluish and banded limestones come in on top of the greenish beds. The limestones are in heavy beds, 2 to 4 feet thick, and quite pure in some layers. No traces of life with the exception of a Stromatopora-like form. The strike and dip of the beds vary; but the section appears to be practically unbroken and to consist of a portion of the "Castle Mountain group" of McConnell. The railroad curves in and out along the strike, following the bends of the Middle fork of the Flathead river. About 7 miles from Belton some reddish beds of calcareous argillite appear along with the greenish beds. There may be 2,000 to 3,000 feet of the limestone.

It will be noted that at the time I thought that this series probably represented a portion of the Castle Mountain group of McConnell. Reference will be made later to this (see page 22).

The notes further state:

One mile and a half east of Paola the red shales (calcareous argillite) appear in a railroad cut. Strike, north 80 degrees west (magnetic); dip, north 30 degrees.

The red and green beds extend east of Essex to Java, where massive bluish limestones appear. In cuts between Java and Bear creek is the limestone. Strike, east and west (magnetic); dip, 20 degrees north. The rocks are evidently the massive Castle Mountain limestones of McConnell. The general strike swings to north 60 degrees east, and the dip decreases to 15 degrees north. Two miles west of Bear creek a syncline and fault occurs that brings up the green and red beds beneath the limestone.

*Nyack Creek section.**—At the head of Nyack creek a fine amphitheater is eroded out of the red beds and superjacent calcareous shales and lime-

* Notes were made September 19, 1895.

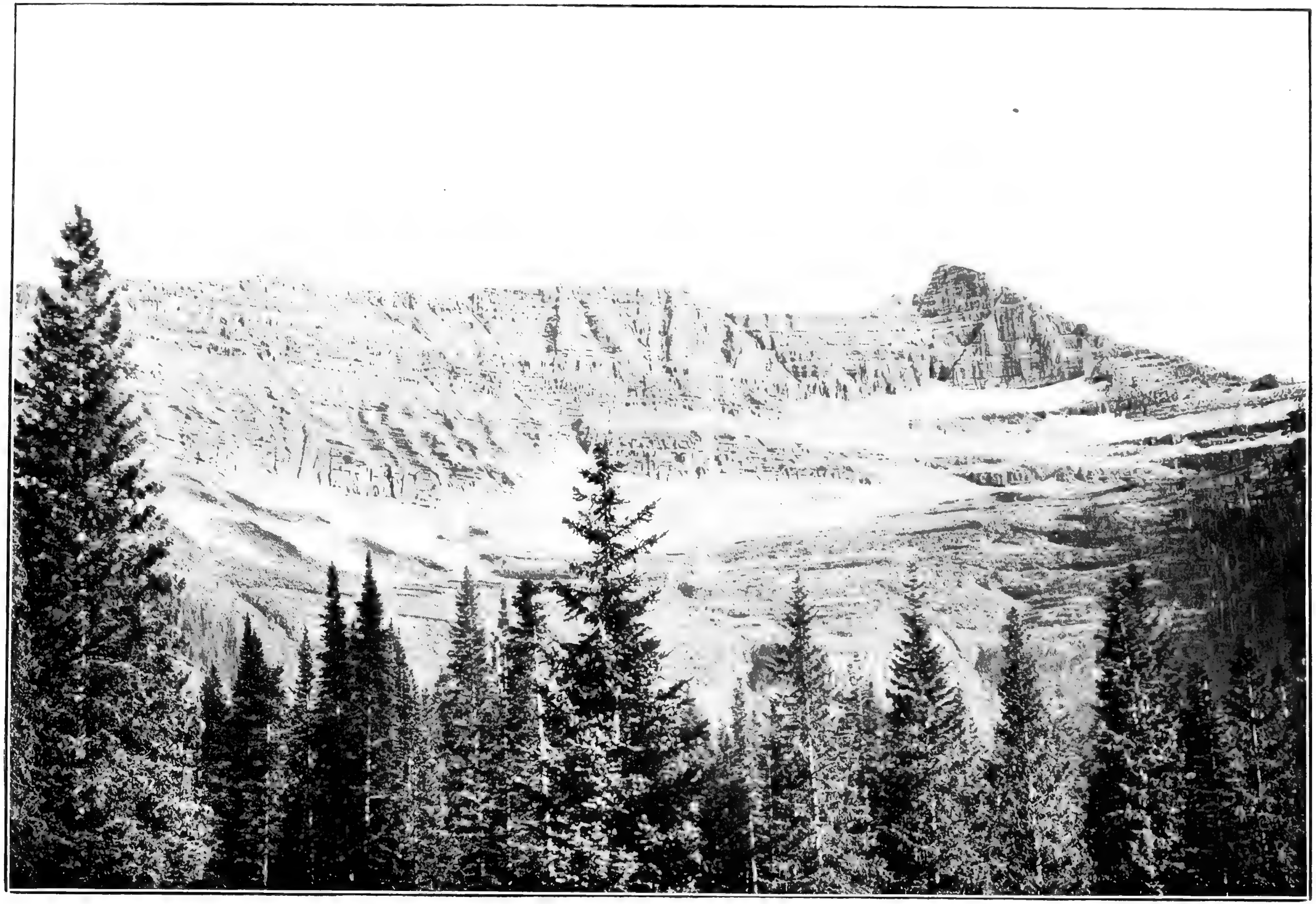
stones. The Castle Mountain rocks form fine ridges and peaks along the Rocky Mountain divide for many miles. There is evidently a fault on the east, as the strata rise and end abruptly as far as could be seen. A species of Raphistoma was found in the shaly limestone 2,000 feet or more above the base of the limestones. Only a few hours were available for the study of this most interesting section, as snow began falling and continued until it was several feet in depth.

This note indicates the presence of the upper red beds of the Camp Creek Algonkian series, with the Cambrian and Ordovician strata above.

GENERALIZED SECTION, CŒUR D'ALENE DISTRICT, IDAHO

The following is a generalized tabular section of Algonkian rocks in the Cœur d'Alene district of Idaho, prepared by Mr F. C. Calkins:

No.	Name.	Description.	Thickness in feet.
6	Striped Peak formation.	Sandstones, siliceous, generally flaggy to shaly; colors mostly green and purple; characterized by shallow-water features, as ripple marks, sun cracks, etcetera.	1,000 +
5	Wallace formation.	Thin bedded sandy shales, underlain by rapidly alternating thin beds of argillite, calcareous sandstone, impure limestone, and indurated calcareous shale; these underlain in turn by green siliceous argillites; shallow-water features throughout; slaty cleavage common.	2,500 +
4	Saint Regis formation.	Sandstones, generally flaggy or shaly; usually fine grained and much indurated; colors mostly green and purple; characterized by shallow-water features.	800
3	Revett quartzite..	White quartzites, generally rather thick bedded; interstratified with subordinate quantities of micaceous sandstone.	1,000
2	Burke formation..	Gray, flaggy, fine grained sandstones and shales, with interbedded purple quartzitic sandstone (the proportion varies widely in different parts of the district) and white quartzite; the formation characterized throughout by shallow-water features.	1,700
1	Prichard slate....	Mostly blue black, blue-gray to light gray slates, generally distinctly banded; considerable interbedded gray sandstone; upper portion characterized by rapid alternations of argillaceous and arenaceous layers, and by shallow-water features; base not exposed.	8,000 +
		Total.....	15,000



LIMESTONES AND SILICEOUS BEDS OF THE CASTLE MOUNTAIN GROUP

Locality is on the Continental divide at the head of Nyack creek on the west and Cut Bank creek on the east, about 25 miles northeast of Nyack, on the Great Northern railway, Flathead county, Montana. C. D. W., 1895

GENERALIZED SECTION FROM STRIPED PEAK, IDAHO

The following is a generalized section of Algonkian rocks from Striped peak, north and northeast of the Cœur d'Alene district, Idaho, prepared by Mr F. C. Calkins:

Formation down.		Description.	Approximate thickness.	Remarks.
No.	Name.			
5	Striped Peak formation.	Sandstones and shales, siliceous, purple, red, and green, with shallow-water features.	2,000 +	Near Heron
4	Wallace formation (equivalent to Daly's Moyie argillite).	Argillites, generally calcareous, blue gray and greenish gray, with thin beds of calcareous quartzite and impure limestone; general composition becoming more calcareous eastward.	5,000 ±	No complete section.
3	Burke-Saint Regis formation (equivalent to Daly's Kitchener quartzite).	Shaly indurated siliceous fine grained sandstones and quartzites; colors gray, greenish, and purplish; some hard white quartzite in Cabinet mountains equivalent to Revett quartzite of Cœur d'Alene district.	8,000 ±	
2	Prichard slate....	Banded dark slates, blue black, blue gray to light gray, with some interbedded gray quartzite.	10,000 ± to zero. 2,000 near Idaho-Montana boundary.	Thickness eastward not recognized by Daly.
1	Creston quartzite (Daly).	Gray, more or less flaggy quartzites, with argillaceous bands.	9,900 +	Daly's figure. Probably thins out eastward.

N. B.—Ripple marks, sun cracks, etcetera, abundant in all formations but Prichard and Creston.

NOTE ON LIMESTONES NEAR KALISPELL

Massive bedded, drab, light colored limestone, breaking up on weathering into shaly layers in some of the beds and in others into irregular fragments with a conchoidal fracture. A few layers of shaly limestone with some arenaceous interbedded layers occur in the series. Near the town, at the quarry, there is about 300 feet in thickness of the limestones exposed. They dip south at an angle of 5 to 10 degrees. The limestones

cover a wide area to the west and south and are apparently interbedded in the quartzite series exposed on the line of the Great Northern railroad to the westward, on the ridge cut through at Haskell pass. Up to date this series may be referred to the Algonkian, although this is probably the same as Dawson's Cambrian to the north, in British Columbia.

These limestones appear to be a portion of the Blackfoot Limestone series of the Mission range.

Unconformity between Algonkian and Cambrian

I have described the unconformity existing between the strata of the Belt terrane and the Cambrian in the Big Belt mountains and in the vicinity of Helena. It was found that in one instance upward of 3,000 feet of Algonkian beds had been removed by pre-Cambrian erosion, and that it was exceptional to find the same Algonkian strata in contact with the Cambrian in localities a few miles distant from each other.* We find similar conditions as the contact of the two systems of strata is traced to the west and northwest. At Lewis and Clark pass the Cambrian rests on a series of reddish brown sandstones, 1,015 feet in thickness, above the Helena calcareous beds. At Helena, 40 miles distant, there are 70 feet of similar sandstones between the Cambrian and the Helena limestone. At the Dearborn section, 10 miles north of Lewis and Clark pass, the Cambrian rests on siliceous and calcareous strata that appear to belong to a portion of the Algonkian section 1,000 feet or more beneath the horizon in contact with the Cambrian at Lewis and Clark pass. In the vicinity of Scapegoat mountain, 35 miles northwest, the Cambrian is superjacent to a series of gray sandstones and shaly beds, 1,700 feet thick, that do not appear to be represented in the Dearborn section.

No contacts with the Cambrian have been observed west of the ridges between the north fork of the Flathead river and the Swan range, although from the presence of Cambrian fossiliferous limestones west of the Mission range such contacts may be found.

Eighty miles north of the Scapegoat area, in the vicinity of Cut Bank pass, at the head of Nyack creek, it is difficult to locate the line of demarcation between the fossiliferous limestones and the Algonkian strata, 2,000 feet below. Further study is needed in this area.

One hundred miles farther north the section appears to be conformable from the Ordovician down through the Middle Cambrian and the Lower Cambrian of the Bow River series, and not to reach down to the Algonkian as it occurs in Montana, the Bow River series being the sediment

* Loc. cit., pp. 210-215.

deposited, in part at least, in the erosion interval between the Algonkian and the Middle Cambrian.

Correlation of Sections

The most easterly section, that of the Belt mountains, has more limestone in proportion to the arenaceous matter and, with the exception of the Neihart sandstone at the base, finer sediments; these conditions indicate that the sediments were derived mainly from a somewhat distant source of supply. One horizon of this section, the Newland limestone, is marked by the presence of fossil crustaceans that also occur in the sections 200 miles to the northwest, as discovered in the Lewis range by Messrs. Willis and Weller,* and Doctor R. A. Daly on the forty-ninth parallel.†

Tracing the upper formations of the Belt terrane north of Helena, we find, at Lewis and Clark pass on the Continental divide, a series of reddish, arenaceous rocks beneath the Cambrian, with some limestone. This is 40 miles from the typical section east of Helena, and there is a manifest change in the sediments, especially in the presence of a greater thickness of arenaceous beds between the base of the Cambrian and the Helena limestone. At Helena the Marsh shales are 300 feet thick, and similar beds at the Lewis and Clark pass give a thickness of 1,015 feet.

The Helena Limestone series in the vicinity of Helena has an estimated thickness of 2,400 feet. It has numerous arenaceous and siliceous bands interbedded with the limestone. By the elimination of a relatively small amount of the calcareous matter the greater part of the limestones would disappear, and a section much like that of Lewis and Clark pass replace the Helena Limestone series.

Ten miles north of the Lewis and Clark Pass section the limestones of the Dearborn section corresponding to those of the Helena series are well developed. The reddish colored shales of the Marsh formation appear to be absent, the Cambrian resting on buff and gray arenaceous beds below the reddish beds of the Lewis and Clark Pass section. The Helena limestone series is represented by 435 feet of siliceous limestones. Below the latter a great thickness of greenish and purplish tinted arenaceous and siliceous beds extend downward 5,700 feet before any more

*Bull. Geol. Soc. Am., vol. 13, p, 317.

† Doctor Daly writes me that the locality is at a point on Oil creek about 6 miles east of the Boundary monument at the summit of the Rocky mountains and about 4 miles north of the line. Through the courtesy of the Geological Survey of Canada, by Doctor Daly, I had the opportunity of examining the specimens. They are identical in appearance and form with those from the Newland and Altyn formations.

Algonkian Sections of Northwestern Montana and Northern Idaho

THE PRINCIPAL HORIZON FOR CORRELATION IS THE FOSSILIFEROUS NEWLAND LIMESTONE OF THE BELT MOUNTAINS SECTION

Belt Mountains, Montana. Walcott	Dearborn Area, Montana. Walcott.	Lewis and Clark Area, Montana. Walcott.	Lewis and Livingston ranges, Montana. Willis.	Camp Creek, Mission Range Section, Montana. Walcott.	North and Northeast of Cœur d'Alene, Idaho. Calkins.	Boundary Section east from Kootenay River. Daly.
Cambrian. Unconformity.	Cambrian. Unconformity.	Cambrian. Unconformity.	No superjacent strata.	Cambrian. Unconformity.	No superjacent strata.	No superjacent strata.
Marsh, 800 feet.	Siliceous and calcareous. 945 feet.	Arenaceous. 1,015 feet.	Kintla. Sheppard. Quartzites. 1,200 feet.	Camp Creek Series. Arenaceous-gray. 1,762 feet.	Striped Peak. 2,000 feet.	Yahk, 500 feet.
Helena. Calcareous. 2,400 feet.	Greenish and purple, arenaceous and siliceous strata. 5,772 feet.	Limestone, 285 feet.	Siyeh limestone. 4,000 feet.	Calcareous and arenaceous. 1,560 feet.	Wallace. Calcareous and siliceous. 5,000 + feet.	Moyie argillite. 3,200 feet.
Empire, 600 + Spokane, 1,500 + Greyson, 3,000 + Arenaceous strata. 5,100 feet.	Base concealed. Total section, 6,718 feet.	Arenaceous. 1,210 feet.	Grinnell. Appekunny. Siliceous. 3,800 feet.	Arenaceous, mostly reddish color. 4,491 feet.	Burke-Saint Regis. Siliceous and arenaceous. Purple, greenish, and gray beds. 4,000 feet.	Kitchener quartzite. 7,400 feet.
Newland. Calcareous. 2,200 + feet.		Base concealed. Total section, 2,510 feet.	Altyn calcareous and siliceous. 700 feet.	Arenaceous red and gray colors. 198 feet of limestone near 700 feet from summit. 3,887 feet.	Prichard. Banded, dark blue gray, blue black and gray. Siliceous series. 10,000 feet.	Creston quartzite. 9,500 + feet.
Chamberlain. Siliceous. 1,500 feet.			Base concealed. Total section, 9,700 feet.	Blackfoot. Calcareous and siliceous. 4,805 feet.	Base concealed. Total section, 25,000 feet.	Base concealed. Total section, 20,600 feet.
Neihart sandstone. 700 feet.				Ravalli. Siliceous and arenaceous. Purple, greenish, and gray beds. 8,255 feet.		
Unconformity. Archean. Total section, 12,000 feet.				Base concealed. Total section, 24,770 feet.		

Total thickness of section of Algonkian rocks in northwestern Montana and northern Idaho, as now known, 37,000 feet.

limestone occurs. This series corresponds to the 5,100 feet of the Empire, Spokane, and Greyson strata of the Belt Mountains section above the Newland limestone. Only the top beds of the latter occur at the base of the Dearborn section.

Continuing northward 120 miles Mr Bailey Willis's section of the Lewis range shows a great development of limestone at about the same horizon as the Helena limestone. This, the Siyeh limestone of Willis, has an estimated thickness of 4,000 feet. It is dark blue or grayish, weathering buff, and contains interformational conglomerates and abundant remains of Cryptozoan, a form unknown in the Cambrian and Ordovician rocks of the Rocky mountains, but which is abundant in the limestones of the Algonkian terranes. The presence of Cryptozoan and also the stratigraphic relations described by Willis indicate that the Siyeh limestone is an Algonkian formation. The series of limestones at the head of Nyack creek, illustrated by plate 6, are of Cambrian or Ordovician age, as indicated by fragments of fossils that I found in them. I do not think the Siyeh limestone is to be correlated with them, nor with the Castle Mountain limestones of McConnell.

The Siyeh (Helena) limestone is overlain by 1,500 feet of arenaceous and siliceous beds corresponding to the arenaceous and siliceous beds above the limestone of the Dearborn section.

Subjacent to the Siyeh limestone there is 3,800 feet of highly siliceous and argillaceous rocks (Grinnell and Appekunny) corresponding to the 5,100 feet of beds of the Empire, Spokane, and Greyson formations of the Belt Mountains section.

The siliceous beds are underlain by the Altyn limestone formation, which by its contained fossils and lithologic characters is identified with the Newland limestone of the Belt Mountains section. Typical fragments of *Beltina danai* of the Newland limestone occur in the Altyn formation; also Cryptozoan. The Altyn limestone forms the base of the Lewis Range section.

The great Camp Creek, Mission Range section begins at a point 35 miles northwest of the Dearborn section and about 85 miles south of the Lewis Range section of Willis. Its upper portions are marked by a great development of arenaceous beds (1*a* of section) above the Helena limestone horizon of the Belt mountains and the Dearborn section.

Below this upper grayish, arenaceous formation there is a thick belt of reddish brown, arenaceous shales (1,560 feet), with more or less thin bedded limestone, alternating irregularly with the greenish gray bands of shales and sandstones, somewhat as in the Helena limestone series.

This is underlain by 5,191 feet of arenaceous beds, mainly sandstones,

largely reddish brown in color, with interbedded belts of grayish red and gray sandstones and sandy shales. The section is here interrupted by a band of compact, impure, siliceous and arenaceous gray limestone 198 feet in thickness. The occurrence of this band of limestone and a thin deposit of calcareous Cryptozoan 500 feet below indicates local conditions favorable for the deposition of limestone.

Below the siliceous limestone there is a great series of reddish gray and reddish sandstones 3,089 feet in thickness. This, with the arenaceous beds above the limestone, gives a total thickness of 8,280 feet, which is interrupted only by the one band of siliceous limestone 198 feet in thickness. This series appears to be a great thickening of the Empire, Spokane, and Greyson formations of the Belt Mountains section.*

The next formation below (Blackfoot) is formed of shaly limestones (see plate 3) alternating with thin layers of gray limestone, 2,500 feet of the thickness of which is largely limestone, with some interbedded and incorporated siliceous and arenaceous material. The lower 1,850 feet is largely a highly siliceous limestone with bands of almost purely siliceous material. This limestone series has abundant remains of Cryptozoan. On the North fork of Blackfoot river the central portions of the limestones are much like those of the Newland limestones of the Belt Mountains section, while in the Mission range, where they are somewhat metamorphosed, they present the bold cliffs and hard, massive, flinty layers characteristic of the cliffs of Altyn limestone of the Lewis Range section.

The Blackfoot series appears to be identical in stratigraphic position and character with the Newland limestone of the Belt Mountains section, and the Altyn limestone of the Lewis Range section, and the Wallace calcareous series of the Cœur d'Alene section of Idaho.

Below the Blackfoot there is, west of the Mission range, a series 8,255 feet in thickness of purple, greenish and gray, siliceous, and arenaceous beds, which completes the section measured by me in the season of 1905. This series, named Ravalli, probably represents that portion of the Cœur d'Alene section between the Wallace and the Prichard series, and it may be a part of the upper portion of the Prichard.

The Cœur d'Alene series does not appear to extend upward to the horizon of the Helena limestone, as there is only 1,000 feet of the reddish beds above the Wallace series which is correlated with the Newland Limestone horizon.

The strata below the Wallace and above the Prichard are correlated with the Ravalli series; and the Prichard, which is composed of dark,

*Mr M. Collen, of White Sulphur Springs, Belt mountains, Montana, wrote me in the spring of 1905 that he had found a marked unconformity between the Greyson shales and the Newland limestone on Birch creek.

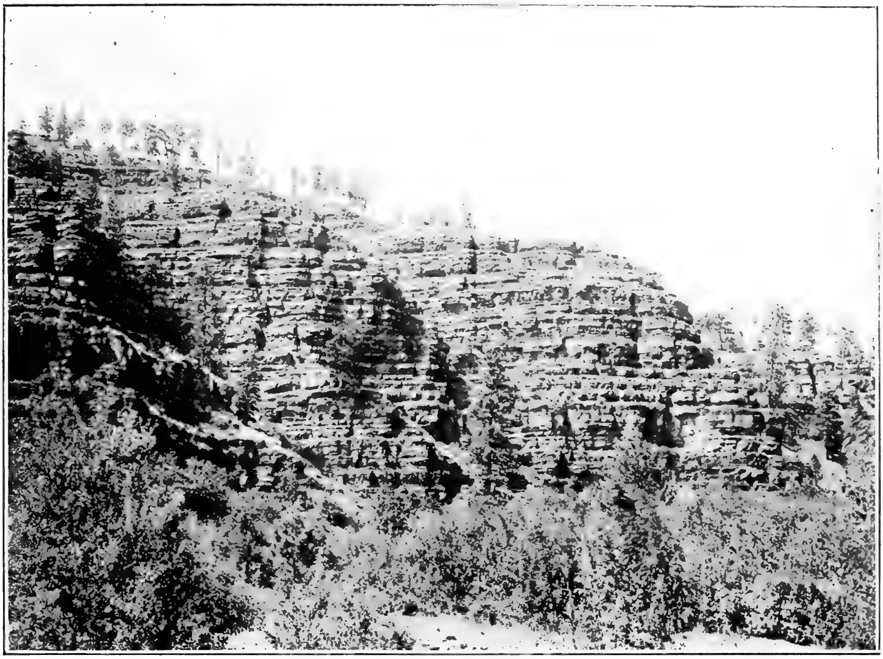


FIGURE 1.—CLIFF OF TYPICAL, BANDED, ARENACEOUS AND SILICEOUS SHALES OF SPOKANE FORMATION

Belt terrane, on Wolf creek, 2 miles below Mitchell, Big Belt mountains, Montana. C. D. W., 1900

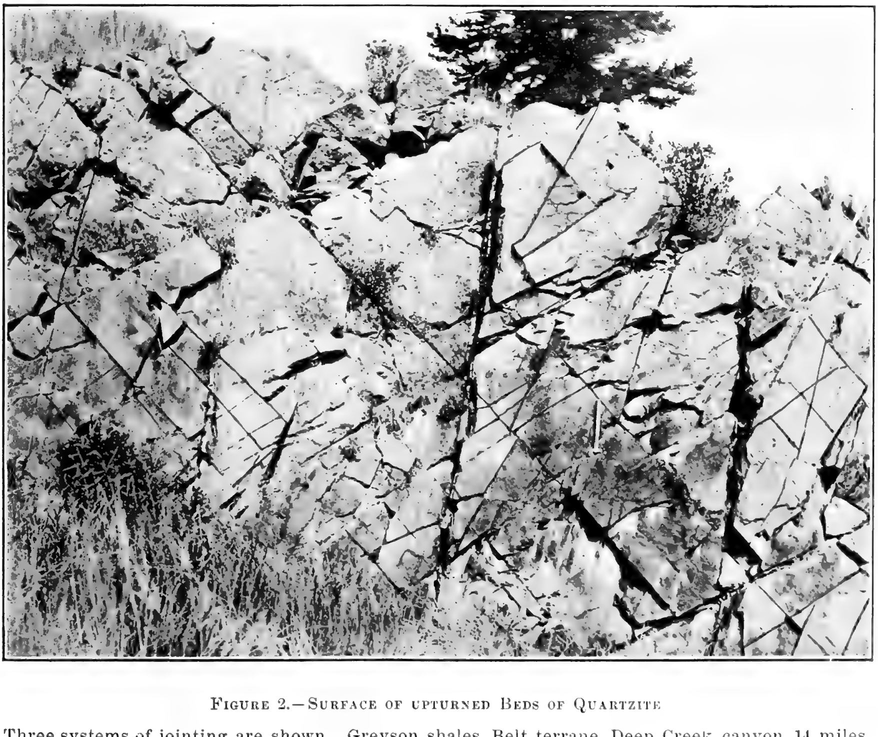


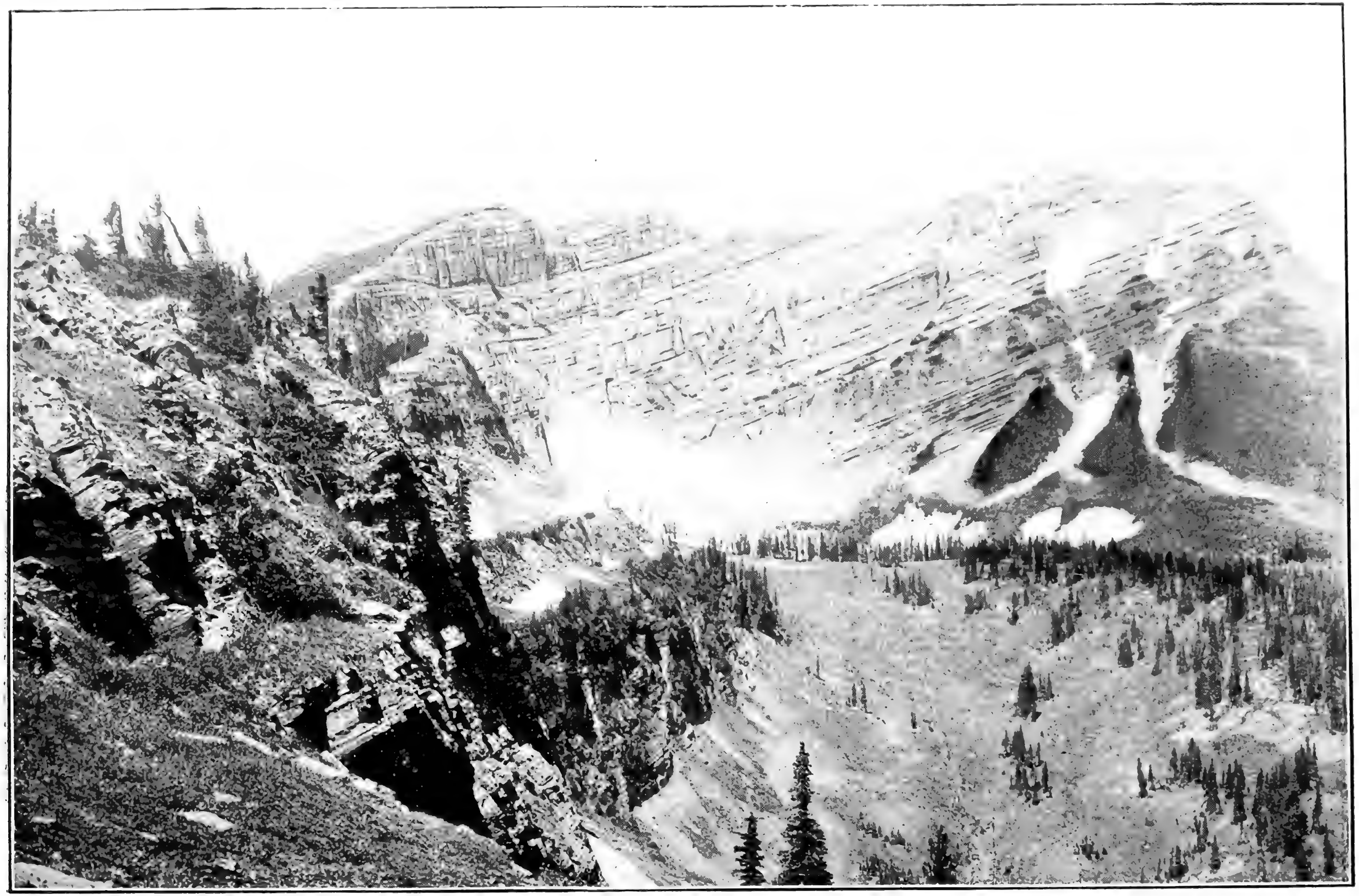
FIGURE 2.—SURFACE OF UPTURNED BEDS OF QUARTZITE

Three systems of jointing are shown. Greyson shales, Belt terrane, Deep Creek canyon, 14 miles east of Townsend, Big Belt mountains, Montana. C. D. W., 1898

SPOKANE SHALES AND QUARTZITE BEDS OF GREYSON FORMATION

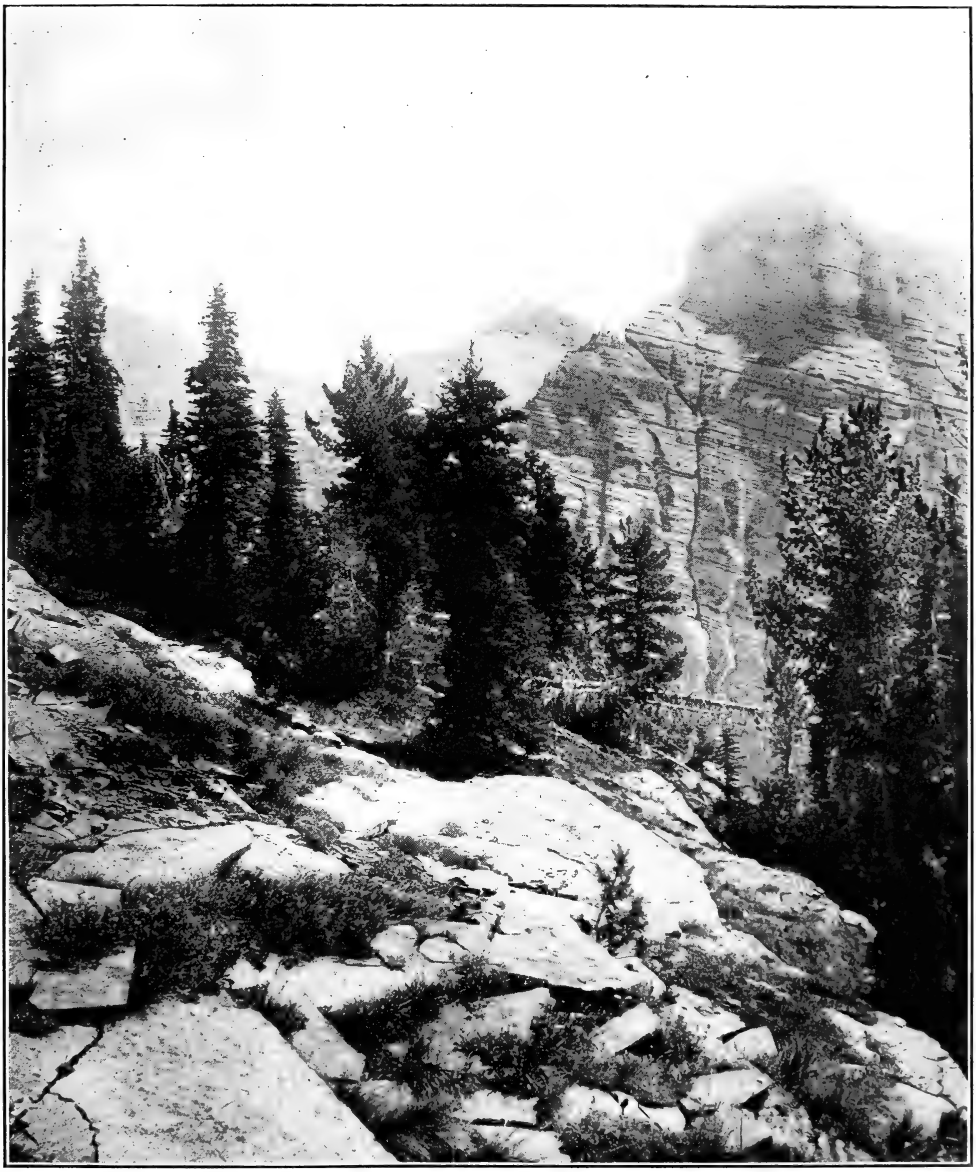
CONGLOMERATE NEAR BASE OF GREYSON SHALES

Belt terrane, Deep Creek canyon, 1 mile east of Townsend, Big Belt mountains, Montana. Indicates unconformity between Greyson shales and Newland limestone. C. D. W., 1898



KOOTNAI PEAK

Latitude 4·° 54′, longitude 113° 56′. Chief mountain quadrangle (Bailey Willis). Mr Willis states that this peak lies about a mile east of the synclinal axis of the Livingston range. The main mass of the peak is formed of the calcareous yellow beds of the Siyeh formation, overlain by maroon-colored quartzites of the Kintla formation. B. Willis, 1901



SIYEH LIMESTONE

General view of the banded phase of the limestone, with ripple-marked slabs of limestone in the foreground. Little Kootna creek, Chief Mountain quadrangle, Montana. B. Willis, 1901

FIGURE 1.—UPPER SURFACE OF A GROUP OF SPECIMENS OF *Cryptozoan frequens* (n. sp.) ON A BLOCK OF SIYEH LIMESTONE.
BAILEY WILLIS

FIGURE 2.—SIDE VIEW OF BLOCK REPRESENTED IN FIGURE 1, SHOWING METHOD OF GROWTH OF *Cryptozoan frequens*
BAILEY WILLIS

SPECIMENS OF CRYPTOZOAN FREQUENS

shaly, and thin bedded siliceous rocks, with the Chamberlain shale horizon of the Belt Mountains section.

The various correlations outlined are represented in graphic form on the table, the horizon of the upper limit of the Newland limestone, at which the crustacean fauna appears, being taken as the horizon from which to correlate the various sections. Of the sections mentioned all but the Lewis Range, Cœur d'Alene, and Kootenay sections are overlain by unconformable Middle Cambrian formations. Only one section, the Belt mountains, has been observed with its base in contact with the Archean.

Correlation of Montanian with Canadian Sections

Mr Bailey Willis has shown the intimate relations between the Boundary section of Dr George M. Dawson and the section studied by him, crossing the Lewis and Livingston ranges.* The formations described by Doctor Dawson are the northward extension of those named by Mr Willis.

The section of Mr R. G. McConnell, across the "Rocky mountains" near the fifty-first parallel, includes the Bow River series and the Castle Mountain group. The latter is a great series of massive bedded, dolomitic limestones, below becoming more shaly, and calcareous above. The included fossils prove the lower portions to be Cambrian and the upper of Ordovician age.

Of the Bow River series Mr McConnell says:†

"The Bow River group forms the basal member of the section in this part of the mountains, and, as developed along the line of railway, consists mainly of a great series of dark-colored argillites, associated with some sandstones, quartzites and conglomerates. The base is not seen, but the part exposed has an estimated thickness of 10,000 feet.

"The argillites are usually dark grayish in color, but become greenish and purplish in places, are very impure, and frequently grade into flaggy sandstones, which are often slightly calcareous.

. . . .

"The conglomerates characterize more especially the top of the formation, and occur in thick, massive looking bands, alternating with quartzites and shales. They are usually firmly cemented into a hard, unyielding rock, but are also met with in a little consolidated and crumbling condition.

"The quartzites, like the conglomerates, are mostly found in the upper part of the formation, and sometimes, as in Cathedral mountain, replace the latter altogether.

. . . .

* Bull. Geol. Soc. Am., 1902, vol. 13, pp. 318-321.

† Geol. and Nat. Hist. Survey of Canada, pt. D, Ann. Rep., 1886, pp. 29 D and 30 D.

"The only fossils obtained from this formation were collected by Dr G. M. Dawson at the summit of the Vermilion pass in 1884, and consist of a couple of trilobitic impressions, one of which has been identified by Prof. C. D. Walcott as *Olenellus gilberti*, a characteristic Lower Cambrian fossil."

My object in noticing the Bow River and Castle Mountain sections is on account of the occurrence of strata that appear to belong to the Castle Mountain group on the Continental divide at the head of Nyack creek, Montana, latitude 48° 30′. These beds appear to correspond to the Cambrian and superjacent groups, as they occur in the Dearborn River section, latitude 47° 15′. On the north fork of Dearborn river the Cambrian sandstone, shales, and limestones rest unconformably on the Algonkian and have a thickness of 2,205 feet. These are overlain by 1,385 feet of limestones referred to the Ordovician and Silurian and 3,255 feet of Carboniferous limestone, a total of 6,845 feet of strata, mainly calcareous, above the Algonkian. It is quite probable that it is the northward extension of the lower portion of this series, that, beneath the Carboniferous, forms the Castle Mountain group at the head of Nyack creek, and also, still farther north, in the section of Mr McConnell. On Nyack creek the calcareous strata are more impure and massive than on Dearborn river, 60 miles south, and they are still more so in Mr McConnell's section, 130 miles to the north.

Another feature is introduced in the Bow River series: If the specimens of Olenellus reported were from the Bow River series, then we have here the Lower Cambrian strata that are absent in the Montana sections, as there the Middle Cambrian strata rest unconformably on the Algonkian.

Doctor Dawson has described a second or western series of "Cambrian" rocks, which he correlates with the eastern section of Mr McConnell.

	Western Section		*Eastern Section*	
Cambrian	Adams lake	25,000	Castle mountain (lower part)	4,000
	Nisconlith	15,000	Bow river	10,000

Of the eastern section he said:*

" . . . Our typical and most carefully surveyed section is that in the Rocky mountains proper or Laramide range, on the line of the Bow River pass. This has been studied by Mr R. G. McConnell, and it is the only section for which some direct paleontological evidence exists.† The base of the Cambrian is, however, not seen in this section. In the Gold ranges, where the Cambrian is frequently found resting on the Archean, the Nisconlith, its lowest recognized

* Bull. Geol. Soc. Am., 1901, vol. 12, p. 65.

† For details of the Bow River Pass section, see Annual Report Geological Survey of Canada, vol. ii (N. S.), part D.

member, varies by several thousand feet in volume, showing that the old surface was a very irregular one and had been greatly modified by denudation previous to the deposition of the Nisconlith. The same circumstance has been noticed by Mr McConnell in the case of the Bow River series of the Laramide range, where it is found resting on the Archean in the vicinity of the Finlay river, over 400 miles northwest of his typical section,* proving this denudation interval to be a very important one, although, as already noted, there is often a parallelism in strike between the two series of rocks."

He then describes the general characteristics of the Bow River and Castle Mountain series, and then says of the Nisconlith series of the western section:†

"Passing now to the next mountain system, to the southwest of the Laramide range and parallel with it—the Gold ranges—we find in the Selkirk mountains a great thickness of rocks that have not yet yielded any fossils, but appear to represent, more or less exactly, the Cambrian of our typical section. Resting on the Archean rocks of the Shuswap series is an estimated volume of 15,000 feet of dark gray or blackish argillite schists or phyllites, usually calcareous, and toward the base with one or more beds of nearly pure limestone and a considerable thickness of gray flaggy quartzites. To these where first defined in the vicinity of the Shuswap lakes the name Nisconlith series has been applied.‡ The rocks vary a good deal in different areas, and on Great Shuswap lake are often locally represented by a considerable thickness of blackish flaggy limestone. In other portions of their extent dark gray quartzites or graywackes are notably abundant. Their color is almost everywhere due to carbonaceous matter, probably often graphitic, and the abundance of carbon in them must be regarded as a somewhat notable and characteristic feature. These beds have also been recognized in the southern part of the West Kootenay district and in the western portion of the Interior plateau of British Columbia.

"The Nisconlith series is believed, from its stratigraphic position and because of its lithologic similarity, to represent in a general way the Bow River series of the adjacent and parallel Laramide range, but there is reason to think that its upper limit is somewhat below that assigned on lithological grounds to the Bow River series.

"Conformably overlying the Nisconlith in the Selkirk mountains, and blending with it at the junction to some extent, is the Selkirk series, with an estimated thickness of 25,000 feet, consisting, where not rendered micaceous by pressure, of gray and greenish gray schists and quartzites, sometimes with conglomerates and occasional intercalations of blackish argillites like those of the Nisconlith. These rocks are evidently in the main equivalent to the Castle Mountain group, representing that group as affected by the further and

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* Annual Report Geological Survey of Canada, vol. vii (N. S.), p. 24 C.

† Loc. cit., pp. 66 and 67.

‡ Annual Report Geological Survey of Canada, vol. iv (N. S.), p. 31 B.
Bull. Geol. Soc. Am., vol. 2, p. 170.
Annual Report Geological Survey of Canada, vol. vii (N. S.), p. 31 B.
Shuswap map sheet, Geological Survey of Canada.

nearly complete substitution of clastic materials for the limestones of its eastern development.

"In the vicinity of Shuswap lakes and on the western border of the Interior plateau, the beds overlying the Nisconlith and there occupying the place of the Selkirk series are found to still further change their character. These rocks have been named the Adams Lake series.* They consist chiefly of green and gray chloritic, felspathic, sericitic, and sometimes nacreous schists, greenish colors preponderating in the lower and gray in the upper parts of the section. Siliceous conglomerates are but rarely seen, and on following the series beyond the flexures of the mountain region it is found to be represented by volcanic agglomerates and ash beds, with diabases and other effusive rocks, into which the passage may be traced by easy gradations.† The best sections are found where these materials have been almost completely foliated and much altered by dynamic metamorphism, but the approximate thickness of this series is again about 25,000 feet."‡

Of the section along the International boundary, Doctor Dawson wrote:§

"A thickness of at least 11,000 feet of sandstones and shales of red, gray, and greenish colors, frequently alternating and including several contemporaneous trap flows, occurs between the Continental watershed and the Flathead river. This series has not been traced into connection with the sections previously described, but it shows some resemblance to the Selkirk and Castle Mountain groups. The occurrence of blackish calcareous argillites and sandstones at the base may indicate the presence of the Bow River series there, while a limestone at the top of the section in this part of the mountains may prove to be that of the Castle Mountain group."||

Doctor Dawson considered all of the Adams Lake and Nisconlith series to be of Cambrian age. From the known presence of upward of 30,000 feet of pre-Cambrian unaltered sediments in Montana and Idaho, on the strike of the strata of the Adams Lake and Nisconlith series, it appears to be more probable that the Nisconlith and most of the Adams Lake (Selkirk) series are of pre-Cambrian age and to be correlated with the Belt terrane¶ as developed in northwestern Montana and northern Idaho.

During the season of 1904 Dr Reginald A. Daly, of the Geological Survey of Canada, studied the section on the line of the International boundary, between the Kootenay river, at Port Hill, Idaho, and the east-

* For the Selkirk and Adams Lake series see references above given for Nisconlith series.

† Annual Report Geological Survey of Canada, vol. vii (N. S.), p. 35 B.

‡ Comprising greenish schists 8,100 feet, grayish schists 17,100 feet. In Bull. Geol. Soc. Am., vol. 2, p. 168, the thickness is given in error at half the above.

§ Loc. cit., p. 68.

|| Annual Report Geological Survey of Canada, vol. i (N. S.), pp. 50 B, 51 B.

¶ Belt terrane is here used to include the entire series of Algonkian rocks as found in the Belt mountains and westward in Montana and Idaho.

ern edge of Tobacco plains. Of this section he said in a preliminary report:*

"These sediments include an extraordinary thickness of conformable quartzite and argillites, the former dominating. The whole group has, on lithologic and stratigraphic grounds, been divided into four series. The lowest series, the Creston quartzite, is composed of 9,500 feet of wonderfully homogeneous, highly indurated, thick-platy gray sandstones. Overlying the Creston quartzite is the Kitchener quartzite, a second series of ancient, hard sandstones and interbedded argillites, carrying a high proportion of disseminated iron oxides. These rusty rocks are, relatively, thin bedded and bear very abundant sun cracks and ripple marks on horizons ranging from top to bottom of the series. The thickness of the Kitchener quartzite is about 7,400 feet. It is itself conformably overlain by at least 3,200 feet of thin bedded, red and gray argillaceous strata which, together with subordinate thin beds of light gray quartzites, make up the formation I have called the Moyie argillite. The youngest member of the four sedimentary divisions is the Yahk quartzite, composed of white to gray indurated sandstones bedded in thin to medium courses. The top of this series was not seen; the whole thickness observed is 500 feet. The total observed thickness of conformable strata is nearly twenty thousand feet. Neither the bottom of the Creston quartzite nor the top of the Yahk quartzite appearing in the sections, it is certain that this great thickness is only a minimum thickness."

"The westward extension of this sedimentary series was mapped and measured during 1903 in the boundary belt immediately west of the Kootenay at Port Hill. There the strata corresponding to the Creston quartzite are conglomerates, grits and coarse sandstones as well as fine grained sandstones, and are thus, on the whole, notably coarser than they were found to be anywhere in this season's belt. The equivalent of the Kitchener quartzite is less strongly charged with argillaceous beds than is the Kitchener quartzite east of the Kootenay. These facts point to the conclusion that the shoreline, whence the materials composing the stratified formations were derived, lay to the westward and that the open sea and deeper water lay to the eastward of the western crossing of the Kootenay river at the International boundary.

"This conclusion was strikingly confirmed on carrying the section towards Gateway. It was found that both the Creston quartzite and the Kitchener quartzite gradually became charged with interleaved beds of calcareous quartzite, calcareous argillite and siliceous limestone, betokening open-water conditions during the formation of these sediments. In fact, the transition of the great quartzite series to certain of the more calcareous formations of the Rocky mountains has become the best working clue to the correlation of the rocks of the Purcell range with those of the Rocky Mountain front. If this conclusion be confirmed by the further eastward extension of the boundary section next year, it will mean that the Creston and Kitchener quartzites and, possibly, also the Moyie argillite and Yahk quartzites are of pre-Cambrian age. The nearest relatives of the Creston and Kitchener quartzites in the Rockies are respectively the two thick members of the Altyn limestone de-

* Summary Report Geological Survey of Canada for 1904, issued 1905, p. 96.

limited by Mr Bailey Willis, who, in the year 1901, carried out a reconnaissance survey of the boundary belt on the Montana side.* No fossils have, as yet, been found in these old rocks of the Purcell range, but fossils of so-called Algonkian age were discovered in the Altyn limestone."

In a letter received from Mr Reginald A. Daly under date of November 3 he says of the work of the season of 1905:

"In general my section for the Livingston range is quite similar to that of Mr Willis, though I seem to have a greater thickness of the Altyn represented—a thickness deduced at a point where there is no suspicion of any considerable duplication by thrusts. The same formations appear in the Galton range west of the Flathead and yet show systematic contrasts in lithologic characters when compared with the rocks of the Livingston range. These changes are at first, as one goes westward from the Great plains, quite gradual, but they quickly mount in value on the sixty-mile section across the Purcell range. In brief they seem to depend, in the large way, upon distance from the old shore-line near the crest of the southern Selkirks not far from Priest River, Idaho. The whole section made through these sediments is 150 miles long, *i. e.*, between Priest River and the Lewis thrust. The section is a cross-section, not only with reference to the present mountain axes, but also of the geosynclinal bearing the sediments. In the Selkirks at the Boundary the latter are coarse and heterogeneous; in the Purcells, medium grained and homogeneous (sandstones, now quartzites); in the Galton and Livingston ranges, fine grained and heterogeneous as described by Mr Willis. Thicknesses are very great at all the best sections. I regret to report no fossils except in the Altyn, though I have searched carefully for nearly three seasons. I am of the opinion, however, that the Siyeh limestone is to be correlated with McConnell's Castle Mountain limestone."

The Creston and Kitchener quartzites appear to belong to the lower portion of the Algonkian section, corresponding to the Prichard siliceous series of the Idaho section, or it may be that the Creston is older than the Prichard. In the diagram of sections I have made a tentative correlation on the basis that all of the Northern Idaho section of Daly is older than the Wallace and Blackfoot calcareous series.

Source of Sediments

The great development of limestone, accompanied by fine grained sandstones and shales, in the Belt mountains, the Rocky Mountain front, and westward to Idaho indicate offshore deposits. To the westward Dr Reginald A. Daly found the strata west of the Kootenay, corresponding to the Creston quartzite, formed of conglomerates, grits, and coarse sandstones, as well as fine grained sandstone. It is also to be noted that

* Bull. Geol. Soc. Am., vol. 13, 1902, p. 305.

limestone is rarely found west of the Mission range, although the siliceous sediments are very fine, often indicating the deposition of siliceous mud rather than sands.

The great source of sediments, as suggested by Doctor Daly, must have been to the west and northwest of the Kootenay valley. A more or less shallow open sea extended eastward 300 miles or more. In the vicinity of Neihart, Montana, there is a trace of the eastern shoreline in the uplift of Archean gneiss and schist, with the basal conglomerate resting upon it. Occasional beds of conglomerate also occur in higher formations of the Algonkian 20 miles and more away from the Neihart Archean. It seems probable that the latter exposure is of an area that was soon buried by the Algonkian sediments, and that the main eastern shoreline, or land area, was still farther eastward during most of Algonkian time. From the character of the Algonkian sediments of the Little Belt mountains it also appears that the eastern land area afforded very little coarse material. It may have been low, sending only muds and solutions of lime and silica to the Algonkian sea, along with an occasional rush of sand and fine gravels.

Summary

The Algonkian rocks which form the subject of this paper represent a total thickness of 37,000 feet and occupy an area extending from the Little Belt mountains on the southeast to the vicinity of Cœur d'Alene on the west and northward into British Columbia. The Camp Creek, Mission Range section occurs near the center of this area and is taken as the type because of its great vertical extent (24,770 feet) and the fact that it is capped by Cambrian strata.

In the four sections measured by the writer the Algonkian or Belt terrane is overlain unconformably by massive, coarse grained sandstones referred to the Middle Cambrian. The unconformity is usually indicated by great changes in the volume of the underlying strata and represents a considerable time interval. From the presence of Lower Cambrian fossils in the Bow River series of McConnell it is believed that this series was laid down during the erosion interval between the Algonkian and the Middle Cambrian in Montana.

The physical conditions under which the Belt terrane was deposited are very clearly indicated by the change in the character of sedimentation from the conglomerates, grits, and coarse sandstones on the northwest to the limestones, fine sandstones, and shales on the southeast. The land area from which these sediments were mainly derived must have

been to the west and northwest of the Kootenay valley at Porthill, Idaho. The sediments which extend 300 miles or more to the eastward betray frequent evidences of shallow water deposition, and in the Little Belt mountains indicate that the eastern land area was of low relief and situated still farther to the east, although the presence of a limited land area is shown by the conglomerates at the base of the Algonkian section near Neihart.

MAP OF ALASKA SHOWING LOCATION OF YAKUTAT BAY

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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RECENT CHANGES OF LEVEL IN THE YAKUTAT BAY REGION, ALASKA*

BY RALPH S. TARR AND LAWRENCE MARTIN

(*Read before the Society December 28, 1905*)

CONTENTS

* The observations recorded in this paper were made in the summer of 1905, in connection with a general geological study of the Yakutat Bay region by a United States Geological Survey party under the direction of the senior author. A grant of money obtained through the assistance of the American Geographical Society made it possible to add the junior author to the party as special assistant in physiographic and glacial geology. Acknowledgments are due to B. S. Butler, the other member of the scientific corps, for assistance in this work.

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Introductory Considerations

EARTHQUAKE OF SEPTEMBER, 1899

The San Francisco *Examiner* for September 25, 1899, contains a letter sent from Yakutat, Alaska, September 17, by the Reverend Sheldon Jackson, giving a vivid but exaggerated account of a series of earthquake shocks beginning September 3 and still continuing at the date of writing the letter. Some of the statements are evidently erroneous, but many

of them were verified by us.* The first shock occurred September 3, and there were shocks at intervals until September 10, when, at 9.20 a m, they began to be alarming. There were 52 shocks, culminating in one of great violence at 3 p m. The land swayed, the waters of the bay rose and fell 8 to 10 feet every few minutes, and violent eddies were set up in the harbor, washing into the sea an Indian burial ground at Port Mulgrave, opposite Yakutat. Most of the natives and whites were panic-stricken, abandoning their houses and retreating to tents on the neighboring morainic hills. There was another violent earthquake September 15, and other shocks until September 20.

A party of prospectors was encamped on the shore of Russell fiord near the Hubbard glacier, and their experiences, as related to us by one of the party, Mr Flenner, were full of excitement and danger. The ground rocked so that they could not remain on their feet; the front of Hubbard glacier was broken into fragments; great water waves washed them and their equipment back on the moraine; a lake, marginal to Hubbard glacier, burst its barrier; and huge avalanches descended the mountain sides. The prospectors finally escaped with such equipment as they could save, though on their way to Yakutat they were again placed in danger by the earthquake of September 15. That the experiences related by Mr Flenner are in the main correct there can be no doubt, and that his party escaped destruction is remarkable, in view of the clear evidence of the cataclysm still recorded along the shores of the bay. So far as could be learned, there was no loss of human life; but at that time of year the natives are not liable to be in the bay, and their village is from 15 to 30 miles or more from the centers of disturbance.

It is a well known fact that an earthquake shock in September, 1899, did such damage to the Muir glacier on Glacier bay, 140 miles southeast of Yakutat, as to render access to it impossible by the tourist steamers for several seasons. It will be most interesting to learn whether the phenomena so clearly recorded around the shores of Yakutat bay are duplicated in the Glacier Bay region.

Although we knew in general terms that there had been an earthquake in the Yakutat Bay region in 1899, we were totally unprepared for the clear and striking proof of it that we found, or for the evidence of the remarkable changes of level which accompanied it. It is the purpose of this paper to state with some fullness the evidence of the changes which were associated with this earthquake and to venture some interpretations based on this evidence. Altogether it is the most remarkable instance of

* The only reason for referring to this is that it is the only first-hand published account of the earthquake which we nave seen.

change of level so far recorded; and the fact that it is possible to assign to it an exact date is of considerable importance.

LOCATION AND GENERAL PHYSIOGRAPHY

Yakutat bay is a deep indentation in the unbroken concave stretch of coastline between Cross sound and Controller bay. This smooth coast is backed by the lofty Fairweather and Saint Elias ranges, which reach their culminating heights in mounts Saint Elias and Logan, 18,000 and 19,540 feet respectively. The mountains do not, however, rise directly from the sea, but are faced by a low foreland, or coastal plain, of glacial debris, broadening toward the northwest, and on the northwest side of Yakutat bay still occupied by the ice plateau of Malaspina glacier. Yakutat bay, which lies about 40 miles southeast of mount Saint Elias, pierces the Yakutat foreland as a V-shaped bay. On its western side the bay is bordered by the low foreland (here glacial gravels from the Malaspina and other existing glaciers); but on the eastern and southeastern sides the foreland forms the coast for only about half its length (see plate 23, opposite page 54). This part of the southeastern shoreline (see plate 16, figure 2) is very irregular and is fronted by an archipelago of low islands of glacial debris. The northern half of the bay has for its eastern shore a mountainous land rising abruptly to elevations of 3,000 to 4,550 feet. This shore is straight and precipitous, and the mountain front, against which the foreland is built, also rises abruptly along a straight line which truncates the mountain spurs* (see plate 22, figure 1).

Yakutat bay merges northward into a narrower arm, called Disenchantment bay, which is a true fiord, walled on both sides by steeply rising mountains. It extends from points Funston and Latouche on the south to Hubbard glacier, which forms its head with an ice cliff about 4 miles in length. A second tidal glacier, the Turner, enters the fiord through a valley in its west wall.

At Hubbard glacier the inlet turns at a high angle, and thence on to its head is called Russell fiord. North, northeast, and northwest of this, mountains rise to elevations of 10,000 to 16,000 feet, but along the immediate shores of the fiord the mountains rise abruptly to elevations of only 2,000 to 6,000 feet. Russell fiord, which extends back toward the Pacific, roughly parallel to Disenchantment and Yakutat bays, is divisible into three sections: (1) a northwest arm, with straight mountainous shores; (2) a longer south arm, with a much more irregular mountainous shoreline; and (3) the head of the bay, an expanded extension of the

* Russell (see Nat. Geog. Mag., vol. iii, 1891, pp. 57 and 83) infers faulting here on the basis of topographic form and geological structure.

inlet where it passes beyond the mountain front out into the foreland. A small bay, Seal bay, up whose valley lies Hidden glacier, forms the greatest irregularity in the coastline of the south arm; but at the angle between the south and northwest arms a large fiord extends eastward, under the name of Nunatak fiord. The tidal Nunatak glacier forms its head.

The entire inlet,—Yakutat bay, Disenchantment bay, and Russell Fiord—omitting its branch, the Nunatak fiord, has the general shape of a bent arm with the shoulder at the Pacific, the elbow at the head of Disenchantment bay, and the fist at the expanded head of the bay where the fiord extends into the foreland to within 13 or 14 miles of the ocean. From the ocean around to the head of Russell fiord by boat is a distance of 70 or 75 miles. Thus our studies extended along more than 150 miles of shoreline in the bay and fiord, all parts of which were seen and most of which were studied critically.

Everywhere the indications are that the fiord is deep. Soundings have been made by the U. S. Coast Survey in Yakutat bay, showing an irregular bottom deepening toward Disenchantment bay. At the mouth of the latter bay, near point Latouche, there is a depth of 167 fathoms; and between Haenke island and Hubbard glacier Russell reports 40 to 60 fathoms. Beyond this no accurate soundings have been made; but the shape of the coast and the absence of kelp indicate deep water throughout the fiord.

GEOLOGICAL STRUCTURE

The northeastern shore of Russell fiord, from Hubbard glacier to Nunatak fiord, is made of highly inclined slates of undetermined age. Our expeditions into the mountains along this shore discovered a variety of crystalline rocks, both igneous and metamorphic, and the glaciers bring down only these classes of rock. All the north shore and the eastern two-thirds of the south shore of Nunatak fiord are also bordered by crystalline rocks—granite, and steeply dipping gneiss, schist, slate and stretched conglomerate. These crystalline rocks end abruptly against a younger, practically unmetamorphosed series both in the Hidden Glacier valley and on the south shore of Nunatak fiord. This line of separation, interpreted as a fault, if continued would extend down the northwest arm of Russell fiord, on one of whose shores the rocks are crystalline, while on the other (southwest) the unmetamorphosed series is present.

From these crystalline rocks to the foreland there is a complex, called the Yakutat series by Russell, forming all the mountains bordering this part of the fiord. It consists of thinly bedded black shales and sandstones,

thick beds of black shale conglomerate, and a massive gray rock which, with the incomplete petrographic work so far done on it, is tentatively classed as an indurated tuff. There are other rocks in lesser quantities, and the entire mass is complexly folded and faulted, both on a large and small scale. Small faults and folds occur in all the outcrops, and frequently a score or more appear in a single outcrop a few square yards in area. The series is literally crushed and "kneaded." The Yakutat rocks are very barren of fossils, and from those which we were able to collect it has not been possible to determine their age. Ulrich* classifies this series as Liassic.

A third series of rocks occurs in a few outcrops two or three miles from the head of Yakutat bay, on the west side. These rocks are mainly gray sandstones, clays, and carbonaceous shales, with some small beds of lignite coal. They stand at a high angle, but are not complexly folded and faulted like the Yakutat series, from which they are apparently separated by a fault. A tentative determination of Pliocene age, based on a preliminary examination of the plant fossils, has been placed by Knowlton on this coal-bearing series.

Outside of the mountain front, as already stated, a foreland of glacial gravels extends to the sea; but near the head of Russell fiord it is underlaid by planated Yakutat series and granitic rocks. Elsewhere no hard rock was found in the foreland; but a low, butte-like hill rising above it some distance from the mountains is evidently rock.

PREVIOUS EXPLORATIONS

Professor I. C. Russell explored Yakutat bay and Disenchantment bay in 1890.† He describes the earlier explorations, discusses the general physiography and geology, and pays particular attention to the glaciers. In 1891‡ Russell extended his explorations to the head of Russell fiord. In his descriptions he clearly points out the faulted and folded condition of the rocks of the Yakutat series and assigns to faulting an important part in the production of the physiography of the region. With the exception of some gravel terraces, which our work leads us to assign to other origin, Russell mentions no elevated shorelines. He does call attention to a submerged forest at the head of the bay which we also saw.

The Harriman expedition visited the inlet in June, 1899, three months before the earthquake, and went to the head of Russell fiord, landing at several points, among others on Haenke island, which now has very dis-

* Harriman Alaska Expedition, vol. iv, 1904, pp. 125-146.
† Nat. Geog. Mag., vol. iii, 1891, pp. 53-203.
‡ Thirteenth Annual Report U. S. Geol. Survey, 1891-2, part ii, pp. 1-91.

tinct shorelines elevated 17 to 19 feet. Among those who landed here was Dr G. K. Gilbert, whose critical studies and interpretations of abandoned shorelines are well known. The fact that he does not mention an uplift there, where the uplifted shorelines are very perfect, is suggestive evidence that they had not then been upraised; and this conclusion is amply verified by other evidence. Doctor Gilbert describes the general physiography of the region, giving especial attention to the glaciers, in his book which forms a part of the series of Harriman Expedition monographs.*

In July, 1901, a U. S. Fish Commission expedition, under the direction of Ensign Cyrus R. Miller, went up the fiord; and while his description gives no information of the change in level which had occurred, one of his photographs* plainly shows a part of the elevated shoreline of Haenke island. He does state, however (page 384) that around the circular lake on the foreland at the mountain base (to which we have given the name Miller lake), the eastern and western shores were covered with dead spruce and hemlock, said to have been killed during the earthquake of September, 1899. This lake lies on one of our inferred fault lines.

GENERAL STATEMENT OF OBSERVATIONS IN 1905

Our work along the shores of Yakutat bay and Russell fiord extended from June 24 to September 2. We found that the shorelines of the inlet had been differentially deformed and the mountain rocks in places shattered by minor faulting. Parts of the coast show no change in level; some areas are depressed; but throughout most of the coast there has been uplift of from one to ten feet. Locally the uplift far exceeds this figure, along one shore attaining a maximum of 47 feet 4 inches. The evidence of these changes is varied and can best be presented under different headings.

Physiographic Evidences of recent Uplift

ELEVATED ROCK BENCHES

At various points about the shores of the fiord, rock benches stand higher than the cutting zone of present waves. They vary in width from a foot or two to 30 or 40 feet, and are planed across all sorts of structures and all kinds of rocks. In numerous instances small streams cascade over their edge, owing to the introduction of the hanging valley condition by the uplift. In general the benches are broadest where the rocks are

* Alaska—vol. iii, Glaciers and Glaciation, by G. K. Gilbert, 1904, pp. 45-70.
† Plate xliv, opposite p. 392, Bull. U. S. Fish Comm., vol. xxi, 1901.

weakest or exposure to wave cutting was greatest. On the promontories they usually form flat-topped benches, and along straight reaches of rocky coast angular notches planed in the rocks, frequently with unconsumed reefs and stacks on the outer margin. These benches (see plate 13, figure 1) often form an opportunity for travel along the coast in places where at the present stand of the sea it is impossible to even land from a boat. In fact, along the present coast many of the headlands rising out of deep water have been so slightly affected by the waves during the brief period since the uplift that even the glacial scratches and polishing have not been removed by the waves, and can be actually traced continuously from above high tide down to and beneath the low-tide mark.

Where the uplift has been slight—that is, not over a foot or two—it is often difficult to distinguish the older benches from those now forming, since they merge into one another; but in most of the fiord the benches are so clear cut, and so elevated, that from these alone one could be certain of the presence of an upraised strand.

Naturally we considered the possibility of other explanations, such as glacial marginal channels and the action of iceberg waves at a time when tidal glaciers extended farther down the fiord; but it required only a little observation to disprove these hypotheses in most places. The widespread and uniform character of the phenomenon, and the almost universal association of barnacles and other marine organisms, still clinging to the rock on the benches, sufficed to effectively dispose of other explanations than uplift.

In two or three places, notably near the Hubbard and Nunatak glaciers, there is evidence of wave cutting at a higher level than at present, apparently performed when the ice-fronts were nearer these shores and the waves generated by calving of icebergs more effective. Such shorelines are not more than two or three feet higher than normal, and are not to be confused with the well defined elevated shorelines, which in reality attain their best development not near, but at a distance from, the tidal glaciers.

ELEVATED SEA CAVES AND CHASMS

Some of the rocks of the Yakutat series, especially the thin bedded black shales and sandstones, yield more readily to wave attack than others, such as the indurated tuff and massive conglomerate. Accordingly the shores of the inlet furnish many instances of sea caves and chasms; but in those parts of the coast where the wave-cut benches are elevated these phenomena are found in association with the uplifted shoreline and not with the present stand of the sea (see plate 13, figure 2). The caves

FIGURE 1.—LOOKING NORTH ALONG EAST SHORE OF DISENCHANTMENT BAY, JUST NORTH OF HAENKE ISLAND

Shows 17-foot elevated rock bench on which barnacles still cling

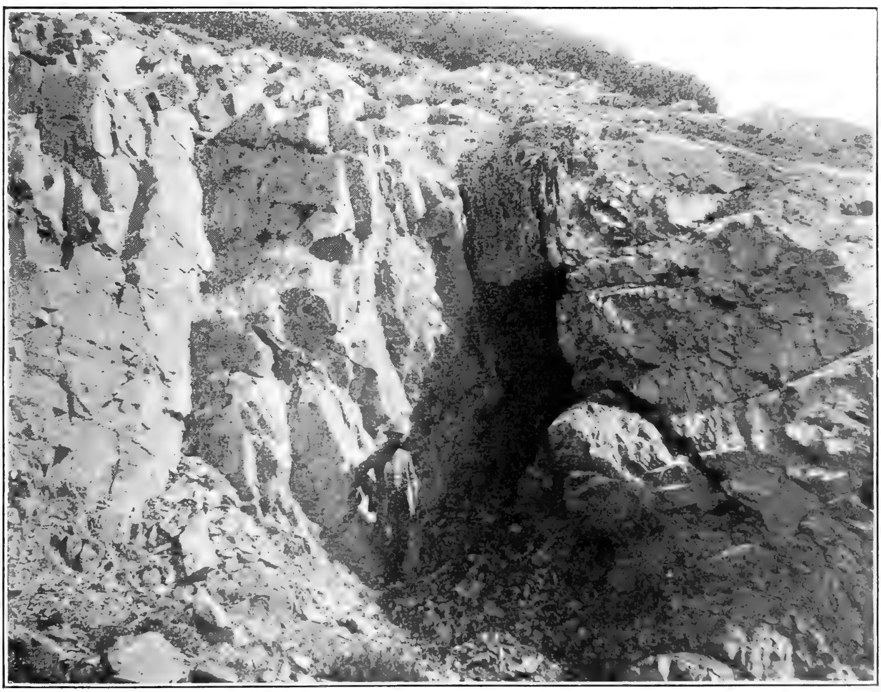

FIGURE 2.—ELEVATED SEA CAVE ON EAST SIDE OF DISENCHANTMENT BAY, JUST NORTH OF HAENKE ISLAND

Uplift is 17 to 18 feet. Base of cave now well above high tide. In middle foreground, below level of cave, is annual land plant

ELEVATED ROCK BENCH AND SEA CAVE, DISENCHANTMENT BAY

FIGURE 1.—ELEVATED BEACH ON ROCK BENCH LEVEL ON EAST SIDE OF RUSSELL FIORD

Locality is 4 to 5 miles south of Russell cove. Elevation here is 6 feet 2 inches. New vegetation in foreground. Old cottonwoods and alders above beach level

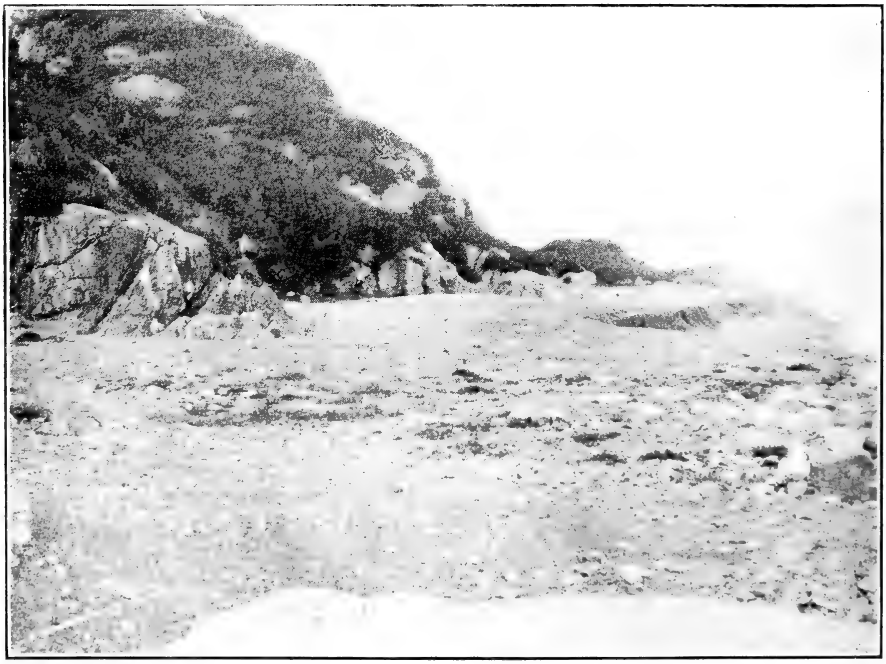

FIGURE 2.—ELEVATED BEACH (37 FEET) ON WEST SIDE OF DISENCHANTMENT BAY, ABOVE POINT FUNSTON

ELEVATED BEACHES, RUSSELL FIORD, AND DISENCHANTMENT BAY

and chasms still contain shingle, but annual plants and even shrubs grow in it, often rising up against and shadowing dead barnacles that still cling to the walls of the chasm—a new life springing up in the habitat of the old. Some caves have been made entirely dry, some only half dry, the tide still rising into their lower portions. One enormous cave, on the south side of Haenke island, rises twice as high above high tide as it did before the uplift, which was here about 18 feet. Waves still enter its mouth, but now never rise high enough to reach the back of the cave. Scores of similar cases were observed in association with the elevated rock benches, and in various places.

ELEVATED BEACHES

Tying bench to bench and foreland to foreland, at appropriate levels, are the perfectly preserved sand, gravel, and boulder beaches of the lower stand of the land (see plates 14 and 15). Excepting near stream mouths, they are all in the form of pocket beaches, for on this straight coast, with rocky shores, limited supply of rock fragments, and deep water offshore, bars and spits have not usually been developed. These elevated beaches vary in perfection of preservation with their height above present tide, position in relation to drainage from the land, and the effectiveness of present wave attack. Some are as perfectly preserved as if they were merely beaches exposed at low tide. An excellent illustration of such a beach lies south of Turner glacier, where there was an elevation of 37 feet (see plate 14, figure 1); and the attack of the waves in the six years of its exposure has merely trimmed its front into a cliff, revealing an excellent beach section of cross-bedded sand.

Some beaches reveal a mere gravel veneer on a rock floor, and are hoisted so high that the waves can not reach the gravel, but are now working on the rock basement. Others are cut back by the waves and deeply gullied, and bid fair to speedy destruction. Still others are almost continuous with the present beach, being separated by only a slight notch (see plate 15, figure 1); and many are actually continuous with the present beach (see plate 15, figure 2), the boundary between the two being merely a line of drifted seaweed or a storm beach, below which grasses and shrubs do not grow. In such places the width of combined old and new beach is often remarkable (see plate 15, figure 2), being in one place fully a hundred yards.

Vegetation grows freely upon these elevated beaches (see plate 14, figure 1), but this will be discussed later. They make splendid camp sites and excellent highways for shore travel, especially at high tide. It is possible to travel on beach and bench for miles, in several parts of the

fiord, where at the former stand of the land travel along the shore at high tide must have been impossible.

ELEVATED ALLUVIAL FANS, OR DELTAS

Practically everywhere that a stream enters the fiord, in places of change of level, there is found a characteristic elevated alluvial fan. Its front is usually nipped away. Its top is dissected by the stream, forced to change from aggradation to degradation by the lowering of its base-level (see plate 16, figure 1). Many streams have intrenched themselves in their alluvial fans from sealevel to the head of the fan, and are now once more aggrading at their mouths and in the lowered channels (see plate 15, figure 1).

Accompanying this change has come a growth of both annual and woody plants upon the upper part of the fan, now no longer reached by the floods of the aggrading stream. As in the case of the elevated beaches, the nipping of the front of the fans varies with the amount of uplift and the intensity of the waves. Another factor is the amount of sediment, for some of the larger streams have built deposits in front of the fans and thus checked the nipping. Some small fans, in areas of marked uplift, have been so nipped as to form pronounced gravel cliffs from 10 to 25 feet in height, and in these cliffs, as well as in the stream cuts, the internal structure of the fans is clearly seen (see plate 16, figure 1).

TILL SHORELINES

At certain places along the present shore, but particularly in the region of marked uplift on the east and west shores of Disenchantment bay, parts of the beach now consist of compact, unoxidized blue till. The occurrence of such a clayey deposit on a beach is evidence of the recency of the movement which exposed it to the waves. How fast the clay is going off in suspension is evidenced by the muddy water along the shore wherever these till shores are wave-washed. They can not last long, for the waves will carry off the clay and round the angular pebbles and erase their glacial scratches; then normal modern pebble beaches will replace these novel ones. At present, however, uplift has brought within the reach of the sea margin the boulder clay which glaciers laid down at a former stage of extension. This boulder clay may be ordinary till or it may be an accumulation of marine silt sprinkled with scratched, angular stones floated in bergs; but its proximity to shore suggests the former explanation. These till shorelines are in all cases found either along rock shores

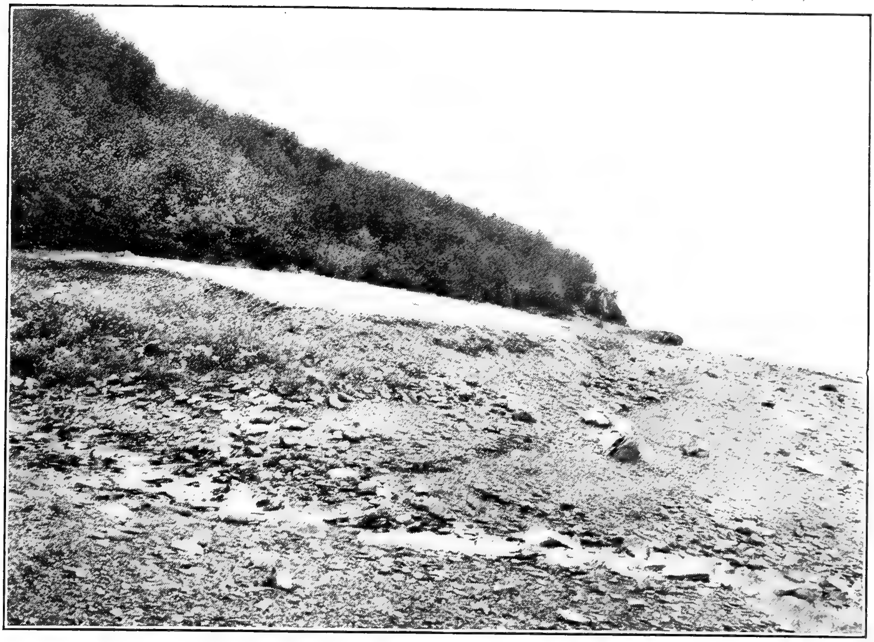

FIGURE 1.—ELEVATED BEACH OPPOSITE MARBLE POINT, NORTHEAST SHORE OF RUSSELL FIORD

The elevated beach is nipped in front by present waves. Mature alder thicket on right. Wave-planed elevated rock bench and sea-cliff in background, with barnacles in place on rocks 7 feet 1 inch above present high tide (see plate 17, figure 1)

FIGURE 2.—ELEVATED BEACH (7 FEET 7 INCHES) ON NORTHEAST SIDE OF RUSSELL FIORD, OPPOSITE MARBLE POINT

Man at square stands with one foot on line of highest drift seaweed, the other on boulder covered with dead barnacles. Present beach on left with no vegetation; elevated beach with young vegetation; and old land (on right) with mature alder thicket

ELEVATED BEACHES, RUSSELL FIORD

FIGURE 1.—DISSECTED UPLIFTED ALLUVIAL FAN HALF MILE SOUTH OF TURNER GLACIER

Showing forest and topset beds. Uplift here 33 feet 11 inches. Figure of man gives scale. Iceberg-borne boulders now rest on crest of uplifted fan

FIGURE 2.—LOOKING SOUTHWARD ALONG EASTERN SHORE OF YAKUTAT BAY ACROSS YAKUTAT FORELAND AT ABOUT HIGH TIDE

Camera stood 1,600 feet above sea. Two of the new islands in Eleanor cove appear at "R"

UPLIFTED ALLUVIAL FAN AND NEW ISLANDS

or else in front of narrow pocket beaches; elsewhere they are doubtless deeply buried beneath beach and delta deposits.

NEW REEFS AND ISLANDS

At a number of places in Yakutat bay and its extensions the depth of the water has doubtless been very materially altered by the changes of level, but unfortunately we have no soundings to demonstrate this. In at least two places, however, new land was raised above the water away from the coastline. One of these, indicated on the map (see plate 23), lies north of Haenke island, forming a menace to navigation. There are two long, narrow islets, the larger approximately 50 feet wide by 250 feet long. Both are rounded, glaciated surfaces rising out of what is otherwise apparently a deep fiord, judging from the freedom with which large icebergs float in it. Formerly no rocks were seen here, even awash at the lowest tides, according to our Indians. Now the reefs are thoroughly uncovered at low tide and not quite concealed when the tide is high. Small icebergs strand on them and are left when the tide goes out, and stones from the melting of these bergs have already accumulated on their surfaces. From the abundance and size of the stranded rock fragments as well as from the seaweed growth on the reefs, it is inferred that these islands were shoals in the bay before 1899, and that icebergs went aground upon them even then.

Near the head of Eleanor cove, southeast of Knight island, and almost at the base of mount Tebenkof, where the mountain and foreland meet, there are four small islands which, according to our Indians, were uplifted during the earthquake (see plate 16, figure 2). Three are of rock, one of gravel, doubtless on a rock core. The two smallest are 50 feet long, the two largest each about 450 feet long and 75 feet wide in the broadest part. Their long axes are parallel and approximately parallel to the mountain front and to the fault which is inferred here (see fault line A, plate 23). They are in fact almost exactly on this inferred fault line. Before 1899 two of these islands were above water at low tide, but none rose above high tide. Now two are visible at all tides, and the other two only between mid and low tide. Thus two new reefs are now exposed, one of rock and one of gravel, and two others, previously visible only at low tide, are lifted above high tide. The highest of these reaches 3 feet above high tide, and on its crest are found dead barnacles in place, thus furnishing testimony of uplift independent of that supplied by the natives.

The Indians pointed out to us a number of places, through which

canoes can not now go, where small islands and stacks were formerly separated from the mainland by navigable water.

AMOUNT OF LAND ADDED BY UPLIFT

We have no quantitative statement to make regarding the amount of land added by this uplift. It is, however, very slight, considering the amount of uplift. The reason for this is that the shores of the fiord in the regions of marked uplift are almost everywhere steep and the water deep. Consequently the new shoreline is separated from the old by a steep grade, sometimes vertical or even overhanging, and rarely less than 30 degrees, excepting on the beaches and deltas. On the deltas and larger beaches the coast has migrated seaward sometimes more than a hundred yards; but such a width of new land is distinctly exceptional. An attempt was made at a rough calculation of the increase in size of Haenke island, where the rock slope is fairly steep, where beaches form only a small percentage of the shore, and where the uplift was marked (17 to 19 feet). This estimate is 25 or 30 feet of new land, on the average, around its entire shore.

Biological Evidences of Uplift

BARNACLES

In most parts of the fiord barnacles are abundant on the rocky shores at present sealevel; but their dead remains are also abundant on the uplifted shoreline, and very often are more abundant there than in the present tidal zone. Two species (*Balanus cariosus,* Darwin, and *Balanus porcatus,* Darwin*) cling to the rocks of the elevated shoreline (see plate 17, figures 1 and 2). Naturally in places of considerable uplift the animals have not grown to such size since the uplift as they had developed before. Among the dead barnacles great forms an inch and a half in diameter are not uncommon; but among the living forms, where the uplift was considerable, three-eighths of an inch was the maximum diameter. In many of the barnacles the inner valves are still held together by the organic tissue, though most commonly it is only the outside shell that remains intact.

These dead barnacles were found on all the uplifted rock coasts where the formation is not too fissile to retain them, and their absence was decidedly exceptional in regions where other evidence suggested uplift. They stand out clearly on the dry rock surface, especially under overhanging cliffs, and are so readily visible from a boat that their presence

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* We are indebted to Dr W. H. Dall for the identification of marine animals collected on the elevated shoreline.

FIGURE 1.—BARNACLES (NEAR KNIFE AND HAMMER) IN PLACE ON SLATE ROCK 7 FEET ABOVE HIGH TIDE

North shore Russell fiord, opposite Marble point. Alders 4 years old hide other barnacles in place

FIGURE 2.—BARNACLES (NEAR KNIFE) AND MUSSELS (ON LEFT) 17 FEET ABOVE TIDE

East shore Disenchantment bay, north of Haenke island (near plate 13). Alders on right and other young plants in crevices of rocks

BARNACLES AND MUSSELS IN PLACE ABOVE PRESENT TIDE

was often an indication of an uplifted section of shore even before the other correlated evidences were discernible. They are very commonly partly hidden by annual plants, and even by alder bushes with from one to five annual rings (see plate 17, figures 1 and 2).

Very often the barnacles were found on boulders on a beach, and it may be pointed out that while such occurrences might be critically rejected as evidence of uplift, because stones covered with barnacles could be thrown up by waves such as accompany earthquakes, in all cases where such occurrences were noted, barnacles were found adhering to adjacent rock cliffs or benches at equally high levels—positions which would preclude such objection.

These barnacles were an important feature in this study—first, because they initially called our attention to the fact of the deformation; second, on account of their function as a quantitative measure of its amount, as stated below. The fact of the presence of dead barnacles fixed to the rock in the midst of grasses and shrubs early attracted our attention. From that we went to the physiographic forms, not well developed on the site of our first observation, and from that to other physiographic evidences, to other biological evidence, and to the human testimony.

MUSSELS

Equally widespread in the fiord, though less abundant than Balanus, is the common mussel (*Mytilus edulis,* L.); and its shells constitute another of the characteristic fossils on the upraised strand. These mussel shells, which turn blue when exposed to the air, were first observed from a boat in Disenchantment bay in clusters about 18 feet above tide water, when we supposed them to be clusters of blue flowers growing in niches in the rock. Later their true nature was determined, and it was found that both there and in many other parts of the fiord the mussels were still clinging to the rocks by their hair-like byssus (see plate 17, figure 2), another evidence of the recency of the uplift. Mytilus, though often present, was not used in measuring elevations, partly because barnacles were always found where any marine life clung to the rock, and partly because the mussels were much less frequently attached than the barnacles.

BRYOZOANS

Below low tide, and in permanent tidal pools, there grows along the shores of the fiord a pink bryozoan, forming a film on the rock, which on exposure to the air turns white. On those parts of the coast which were upraised more than 10 feet, patches and bands of this bleached organism clinging to the upraised cliffs form a prominent feature, often visible

at a distance of 2 or 3 miles, giving the appearance of a whitewashed rock surface (see plate 18, figure 1). In places it still extends below the water, but in two or three sections it has been hoisted entirely out of the sea. Usually the top and bottom borders are fairly horizontally in definition; and the painted appearance of the rocks is recognized even by the natives as an evidence of uplift. This whitened surface is seen especially clearly south of Turner glacier, though it is visible in several other parts of the inlet. Abundant fossils, especially Mytilus (see plate 18, figure 1) and Balanus, occur in the whitened zone and generally extend several feet above it.

OTHER MARINE ORGANISMS

The only other marine animal found clinging to the uplifted shorelines, in such a position as to leave no question of its being in place, was the limpet (*Acniœa pelta,* Esch.). In a few instances the limpet shells were found still adhering to the rock in little protected pockets; but most of those observed on the high level shorelines were not in place and might therefore have been carried up by birds or washed up. The same is true of fragments of crabs, skeletons of fishes, and both fragments and perfect specimens of sea-urchins (*Strongylocentrotus dröbachiensis,* Mull.). Lying loose along uplifted shorelines they are not absolute evidence of change of level; but their abundance and association with other indisputable biological evidence (notably barnacles still fastened to the rock) render these other marine forms valuable as correlative evidence. A more satisfactory case was the finding of several arms of a starfish (*Heliaster* Sp.) by digging in a little rock crevice, to whose sides Mytilus was adhering in abundance, on a rock bench nineteen feet above present sealevel.

A careful search failed to discover any rockweed or other marine plants on any of the elevated shorelines, either loose or in place. That in six years these plants should have entirely disappeared by decay was to us most unexpected; but it seems nevertheless to be the case.

MINGLING OF LAND AND SEA LIFE

As previously stated, vegetation has found a footing where marine forms still cling to the rocks. Thus we find the unusual occupation of the same area by plants which can not live in salt water and animals, still in place, which can not exist without it, although all of the latter forms are dead. Besides the grasses and flowering annuals, shrubs have already sprung up, especially the willow and alder. These woody plants are notably small ones. Among numerous willows and alders which we cut down

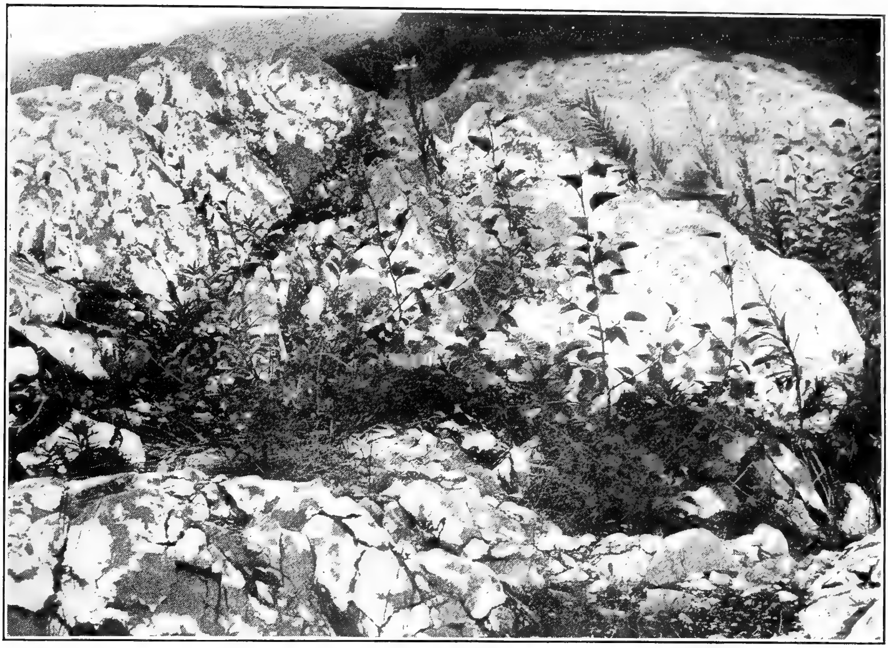


FIGURE 1.—WHITE BRYOZOAN FILM ON 40-FOOT ELEVATED SHORELINE

West side Disenchantment bay, about 10 feet below highest dead barnacles. Many mussels in place. Alders not over 4 years old

FIGURE 2.—ALDERS AND COTTONWOOD KILLED BY SEA ENCROACHMENT

Southeast side of head of Russell fiord. Fourth of mile to the northeast the coast is elevated 7 feet 4 inches

to determine their age, it is notable that none showed more than five annual rings, and most of them had but three or four, which of itself is fairly clear proof of the association of the uplift with the earthquake of September, 1899, six years before.

One willow tree, growing on one of the most perfect of the elevated beaches (hoisted 42 feet), near Black glacier, threatened to prove an exception, for it was 10 feet high and fully 3 inches in diameter. Cutting it down, we found its heart made of dead wood, with four new rings outside. Evidently it was an uprooted tree, thrown there by the earthquake wave, and sprouted in its new location.

PARALLEL LINES OF DRIFTWOOD

On certain of the elevated beaches driftwood had accumulated previous to the uplift; and lower bands have been piled up at the new stand of the land, so that parallel lines of driftwood mark the amount of uplift. These are particularly clear near the head of Russell fiord, where driftwood is abundant. Vertical measurements between these lines, with the Locke level, form part of our quantitative determination of the deformation. In most cases these measurements correspond with dead barnacle levels on the adjacent rock shores, thus checking the determination and proving the validity of the driftwood evidence of uplift. In two or three cases, however, where no barnacles could be found in place, our measurements are based solely upon the parallel lines of driftwood.

DESTRUCTION OF LIFE

That the violent earthquake shocks destroyed much marine life is probable, and the natives assert that after the shocks the shores were lined with dead fishes. The water wave also did much destruction on the land bordering the shore, as will be shown later; but the most widespread destruction now visible is that of the life on the strip of coastline between the old and new sealevels. Here, of course, the destruction was practically absolute. Nearly everywhere the old forms are again developing in their normal habitat, newly located for them; but on all the coasts that were uplifted 10 feet or more the evidence is clear that many forms of life have been forced to begin anew in a zone which they did not previously occupy. This is proved by their small size and relative scarcity. The difficulty of starting anew is in some places increased by the smoothness of the glaciated rock surfaces at present sealevel. On numerous points, notably near Haenke island, seaweed has been able to take hold only along joint planes, and it grows therefore in short, narrow lines of small individuals.

South of Turner glacier, where the uplift was 33 to 47 feet, while dead Mytilus and Balanus are abundant all along the abandoned strand, not an individual of either, nor any of the seaweed (rockweed) so common elsewhere in the fiord were found growing at present sealevel. Here the destruction for nearly 4 miles was absolute, and in the six years since the uplift the common forms of shore life have not yet advanced upon this part of the coast. There are three apparent reasons for the failure of life to advance on this coast from other parts of the fiord: (1) the ice barrier of Turner and Hubbard glaciers to the north; (2) the sand and gravel-shore barrier to the south; and (3) the presence of an outmoving current of water, due to the glacial streams from Hubbard and Turner glaciers, and therefore coming from a region in which these marine forms are absent.*

One is impressed by such evidence with the important effect of changes of level on life, and of its possible influence on extinction of species and change of environment in regions of unstable coastlines during the geological past.

Human Evidence of Uplift

GENERAL EVIDENCE OF RECENCY

The human evidence of deformation of the shorelines has its value largely in the fact that it checks our conclusions upon two important points: First, that the elevation took place in connection with the 1899 earthquake; second, that all the movement was at once (that is, in the same month). The condition of the beaches, benches, and fans suggests that the movement was recent and that it occurred essentially at one time. The uniform perfection of preservation of certain of the marine forms points to the same conclusions. The fact that vegetation seems to have encroached on all parts of all the beaches at once (equally old plants at all levels and all parts of each beach) points to a single period of uplift; and the fact that of these plants none were found that exceeded five years in age is very definite confirmation of the conclusion that the uplift occurred in 1899.

NEGATIVE EVIDENCE OF THE HARRIMAN EXPEDITION

It has already been stated that the Harriman expedition, with a corps of trained observers, including Dr G. K. Gilbert, was in the bay about three months before the earthquake. They report no evidence of recent uplift, although they landed on parts of the coast where uplifted shore-

* We are not certain that they are absent between Turner and Hubbard glaciers, for we did not visit that coast; but from a distance this coast appeared to be occupied by alluvial fans, on which neither barnacles nor mussels could thrive.

lines are very clearly preserved, as did Russell in 1890 and 1891; and both Russell and Gilbert are widely known for their studies of abandoned shorelines. Moreover, the Harriman ship, the *George W. Elder,* sailed twice very close to the site of the present uncharted reefs north of Haenke island. In the absence of other evidence, these facts might not be considered conclusive scientific proofs of the absence of uplifted shorelines in June, 1899, and they are therefore offered merely as suggestive facts bearing upon the question.

NATIVE TESTIMONY

The natives, however, tell us definitely that the uplift took place in the fall of 1899 and in connection with the earthquake at that time. They assert, moreover, that there has been no movement since then, and that there had been none in recent years before 1899.

Natives notoriously tell you whatever you want them to, especially if they can not speak your language well. Therefore in questioning the natives care was taken not to suggest by a question the answer desired. We were fortunate in having with us an exceedingly intelligent and well educated native, J. P. Henry, a Sitka Indian, long resident at Yakutat, who both spoke and wrote English well. Again and again he pointed out to us places, even before we reached them, where changes of level had occurred. He took an intelligent interest in our work and helped us materially; and in all the many cases where verification was possible we never once found him making misstatements. He, and our other native by his translation, told us of the earthquake; of the fish left stranded by the receding sea (some doubtless thrown up by the earthquake wave); of the appearance of new islands; of the uplift of beaches and sea caves; and of the whitened bryozoan film—all striking changes between the two seal hunting seasons of 1899 and 1900.

No uplift took place at Yakutat, where the whites live. These white men seldom penetrate the inner bay, and, with the exception of one or two prospectors, appear to know nothing of the details of the change of level, nor to care about it. One of the prospectors, W. H. Thompson, who knows the bay well, verified the testimony of the natives. But since the Indians hunt seal up the bay every spring, especially in Disenchantment bay, where the uplift was greatest, and are familiar with the coastline in intimate detail, their clear and definite statement as to the time of occurrence of the change requires no corroboration, once we are convinced that their testimony is honestly given, as is undoubtedly the case in this instance. As has been shown, however, even this clear and definite testimony is but one of a series of proofs, all of which point to September,

1899, as the time when, during a series of vigorous earthquake shocks, the remarkable deformation of the coastline of Yakutat bay, Disenchantment bay, and Russell fiord took place.

Evidence of Depression

Less varied in character, yet equally conclusive, is the evidence of depression, shown on a much smaller stretch of coast and naturally masked by the sea. The encroaching of beach sand on forest and the consequent killing of trees by sand-smothering, and by salt water reaching their roots, is especially well seen at the head of Russell fiord (see plate 18, figure 2).

In a number of places on the islands and shores of the foreland on the southeast shore of Yakutat bay this encroaching of the sea is also well seen. The best instance in this vicinity is on the south shore of Knight island (see plate 19, figures 1 and 2), where beach sand extends back into the spruce forest a hundred feet or more, and where waves of present storms are overturning great trees and piling their wreckage among the living spruce. Here also the rank, sedgy beach grass is found growing back in the forest, illustrating once more the battle for the shore strip between land plants and sea or shore forms. As has been stated (page 35), Ensign Miller speaks of dead trees on the shores of Miller lake; but their relation to the lake is not made clear.

None of the instances of depression can be referred to encroachment by waves, for they occur not on the exposed, but on the lee coasts. That it is actual depression of the surface is proved by the fact that over considerable areas tree roots are now bathed by salt water. It is not certain, however, that all these areas of depressed surface are actual instances of a downward movement of the crust. They all occur in unconsolidated deposits, and the depression may be due to a shaking down of these loose beds during the earthquakes. This, however, does not seem probable, since the trees are not thrown down, nor even inclined, excepting where the waves are now undermining them. That the change is a recent one is proved by the fact that many of the trees reached by the storm waves are as yet only partly dead, some of their branches still supporting the needle-like leaves.

Regions of slight or no Movement

Long stretches of coastline were not moved either up or down; but it was often difficult to be certain that there had been absolutely no movement, since a change of a foot or two one way or the other would leave only faint and uncertain evidence of the movement. In these cases simply

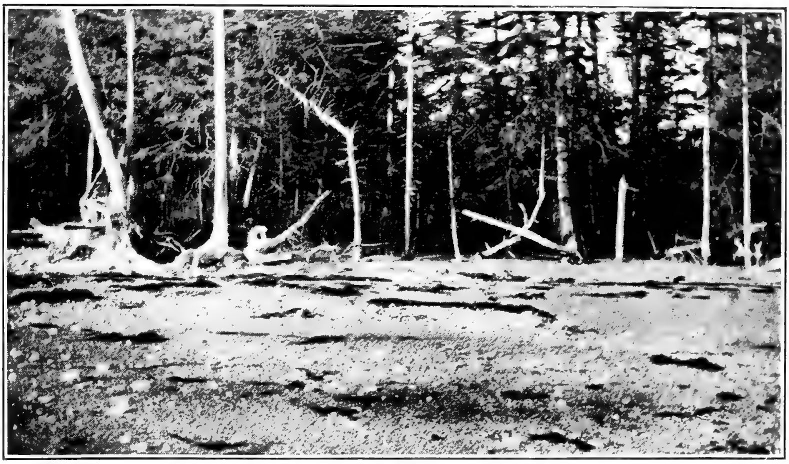


FIGURE 1.—SUBMERGED FOREST, SOUTH POINT OF KNIGHT ISLAND

Dead trees and beach gravel thrown back into forest among trees not completely dead. Submergence about 5 feet

FIGURE 2.—SUBMERGED FOREST, SOUTH POINT, KNIGHT ISLAND

Beach gravel in the forest and beach grass growing in forest edge

SUBMERGED FORESTS, KNIGHT ISLAND

negative evidence had to be resorted to. With no dead barnacles, no discordant beach or bench, no encroachment of sand on vegetation, it was assumed that the stand of the land had been maintained. For most of the area this assumption is undoubtedly correct; because the lack of evidence of change is characteristic of certain coasts, notably on the foreland, in a part of Russell fiord, and in Nunatak fiord.

The latter case may be taken as typical of those places where negative evidence suggests no change of level, though there may have been a very slight uplift. For a mile from the glacier, along shores from which the ice has retreated since the earthquake (proved by a comparison of photographs taken in 1899 and 1905), there is no rock bench at all and little marine life. For the next mile and a half there are no dead barnacles or other marine animals, though there are many living barnacles between tides; but the higher growing seaweeds were bleached or crisped as if by a drought. This was seen nowhere else in the bay. It is probable that they would be revived by the next spring tide. For the succeeding 2 or 3 miles there is a rock bench a trifle too high for present wave work, but possibly formed by iceberg waves when the glacier front was nearer. A few dead barnacles were found, but none that we could be certain were above the level of neighboring live ones. Along this coast we were not certain whether there had been no change at all or a slight uplift; but we were convinced that the uplift, if any, did not exceed a foot.

With the facts observed and the instruments at our disposal we could not make more definite determinations in such places. Consequently we wish it to be understood that on many of the coasts where no quantitative statement of uplift or depression is given we do not mean to assert that there has been absolutely no change, but merely that we could find no conclusive proof of such change. Where the evidence suggests the probability of a slight uplift or depression, the plus (+) or minus (—) sign, with a query (?), is placed on the map (plate 23).

Effects of the Earthquake

IN GENERAL

Besides the results of the earthquake mentioned in the opening section of this paper, there are some effects still visible along the fiord which call for a word of description. They are of two classes: (1) abundant avalanches; (2) wave-swept areas.

EARTHQUAKE AVALANCHES

As in other mountain regions, avalanche effects are visible in many parts of the mountains surrounding this fiord; but they are locally far more

abundant than normal, and without any evident association with peculiarly favorable rock conditions. Moreover, they reach their best development in sections where other evidence suggests the neighborhood of a fault line to a steep mountain slope. The most abundant avalanches, far exceeding in number any seen in equal area either on the 1,000-mile trip up the Inside passage or elsewhere in the Yakutat Bay region, occur along the mountain front near Knight island, and thence northward along the mountainous shore of the east side of Yakutat bay to point Latouche. The Indians report that "the mountain face was here entirely changed in 1899;" and the vast extent of avalanches, involving hundreds of thousands of tons of rock, leads one to accept this statement as, in general, accurate.

Along the shores of Disenchantment bay, also in a region of inferred faulting, there is an excess of avalanches; but the absence of forest here makes their presence less clear and striking. We fortunately have a photograph taken here in 1890 by Russell, looking into the valley of the Black glacier 4 or 5 miles south of the Turner glacier, and at the point where, within a mile and a half, there is a change from a shoreline with no uplift to one uplifted 42 feet. A comparison of this photograph with the condition in 1905 shows remarkable changes, far in excess of what would be expected from normal weathering in 15 years. Great areas of alder and grass-covered slopes have disappeared; talus slopes are noticeably enlarged; and the mountain face is materially altered in detail.

In marked contrast is the series of hanging glaciers, not far away, south of the Turner glacier, delicately poised on the precipitous mountain side 1,000 feet or more above a shore which was uplifted 33 to 47 feet, none of which fell in 1899. One of these did slide out of its valley, however, while we were in the bay in 1905. This indicates moderate disturbance at points away from the actual fault lines.

WAVE-SWEPT AREAS

That earthquake water waves were generated by the shocks of 1899 is proved by the testimony of the natives, of the prospectors who were encamped near the Hubbard glacier, and of the white residents of Yakutat. Throughout most of the inlet no evidence of destruction by these waves is found; yet in places the evidence of a destructive water wave is very clear. Parts of the shores of the fiord are unfavorable to the preservation of records of such waves, but many sections are very favorable and yet show no evidence of an earthquake wave. For example, the low, wooded shores of Knight island show little or no signs of disturbance by the earthquake

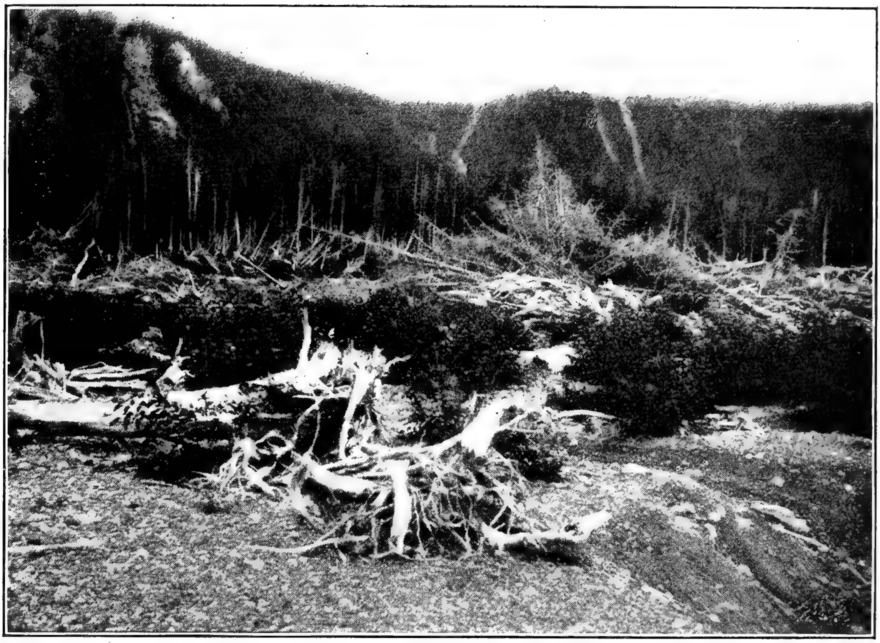


FIGURE 1.—FOREST, 40 FEET ABOVE SEA, DESTROYED BY EARTHQUAKE WATER WAVES

East shore of Yakutat bay, mile and a half north of Logan beach. Avalanches show on mountain face

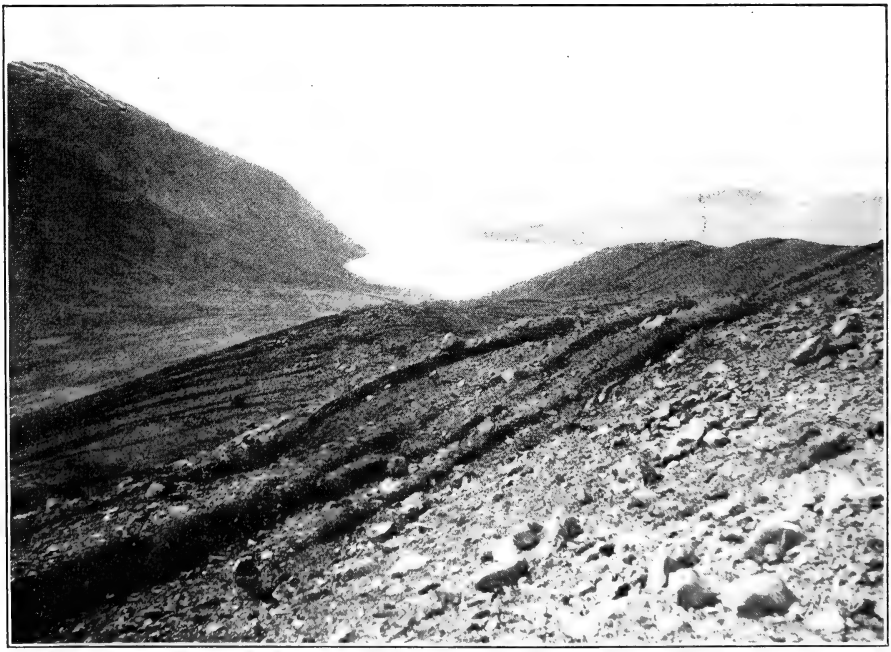


FIGURE 2.—PARALLEL FAULTS, 2 TO 10 FEET APART, GANNETT NUNATAK, HEAD OF NUNATAK FIORD

View westward out of fiord on south side of Nunatak. Faults extend north 40 degrees west (true)

DESTROYED FOREST AND PARALLEL FAULTS

wave, while north of there, half way to point Latouche, the forest is swept away over a considerable distance (plate 20, figure 1).

It is inferred from these facts that the destructive earthquake wave was local in its effects, and it is noteworthy that the two places where it has left the clearest records of its destructiveness are along the lines where we have the best evidence of faulting, namely, along the east shore of Yakutat bay, between Knight island and point Latouche, and on the west shore of Disenchantment bay, near Black glacier.

In the latter place, about at the southern end of the high-level shoreline which extends up to Turner glacier, the cottonwood forest ends abruptly approximately a quarter of a mile back from the shore, along a line which is fringed with piles of dead trunks at an elevation of 30 feet vertically above the driftwood line of the present storm beach. That this is not an elevated shoreline is proved by the fact that between it and the coast is an old dead cottonwood tree in place, eroded of its bark at the level to which the driftwood reaches, and with a little pile of driftwood on its northern side. Between this and the bay are many mature dead willows in place with dead shoots broken and bent southward.

A still clearer instance of destruction by the earthquake wave is found just north of Logan beach, about half way between Knight island and point Latouche (plate 20, figure 1). Here the present beach is littered with trees, often with branches and roots still clinging; the elevated beach is also covered with forest debris; and a still higher, older elevated beach, on which a mature forest had grown, has had its forest almost completely stripped off. Even beyond this there is a wild confusion of fallen and partly fallen trees. There is, in one locality, absolute destruction of timber up to 40 feet above sealevel; and between it and the present shore there is a tangle of fallen trees. The trees are overturned, twisted, broken, and uprooted, giving rise to such a scene of devastation as only rushing water could produce. Being evidently along a fault line, it is probable that the devastation by the tidal wave was assisted by a preliminary shaking of the gravelly soil, which rendered the uprooting of the trees here easier than in other situations.

At cape Stoss, near the head of Russell fiord, there is proof of the passage of a water wave across the low neck of land which joins the rocky cape to the mainland. This proof is the presence of enormous quantities of driftwood on the neck at levels well above that of the upraised shoreline at this point. In one place the driftwood is wrapped around an enormous boulder near the highest part of the neck and several hundred yards from the beach. The natives report that here, and in other places, their best wild strawberry beds were destroyed during the earthquake, and have not

since developed to their former condition. We found other less definite evidence of the recent presence of a destructive water wave in several parts of the fiord.

EVIDENCES OF RECENT FAULTING

RECENT FAULTS ON GANNETT NUNATAK

At several places small faults of recent date were observed. The best and most typical instance is that on Gannett nunatak, which separates the land and sea ends of Nunatak glacier at the head of Nunatak fiord (see plate 23). This rock hill, reaching an elevation of about 1,450 feet, is made of steeply dipping gneisses and schists, striking northwestward approximately parallel to the major axis of the Saint Elias chain. The nunatak is double crested, and the southern half is crossed by scores of small faults (plate 20, figure 2), extending continuously from a few feet to over 200 yards, and with throws varying from an inch to 3 or 4 feet (plate 21, figure 1), but usually less than a foot. They extend approximately along the strike of the rock (north 40 degrees west, true north), but some small faults diverge from it, and a few short ones extend at right angles to the strike, connecting neighboring strike faults. The hade is nearly vertical, and in almost all cases the southwestern side of the fault is the upthrow side, though there are a few with an upthrow on the northeastern side. There are some fissures (plate 21, figure 2) and a few instances of small graben blocks (3 to 30 feet wide) between parallel faults (plate 21, figure 2). Some of the faults were traced up to the glacier under which they apparently passed.

Glacial scratches extend up to the edges of the faults and are there dislocated, and no striæ occur on the faces of the fault-scarps. Here and there the faults have dislocated a thin till veneer on the rock. These facts prove that the faults have developed since the ice receded from the slopes of the nunatak, not many decades ago, and possibly since Russell first saw it in 1891. That they are very young is proved by the sharp angles formed where the fault planes intersect the surface, even when the surface material is till, and by the general absence of notable talus slopes at the base of the tiny fault-scarps. It seems incredible that these fault-scarps can have been exposed to the weather longer than six years; and, although it can not be more positively demonstrated, this faulting is confidently correlated with that deformation of the crust which elsewhere in the region has been definitely determined to have occurred in 1899.

RECENT FAULTING AND AVALANCHES

Our first observations of minor faulting and rock fracturing were made near the edge of a cliff just southwest of cape Enchantment; but the posi-

FIGURE 1.—FAULT SCARP (3 FEET) ON GANNETT NUNATAK
Cliff extends north 40 degrees west (true)

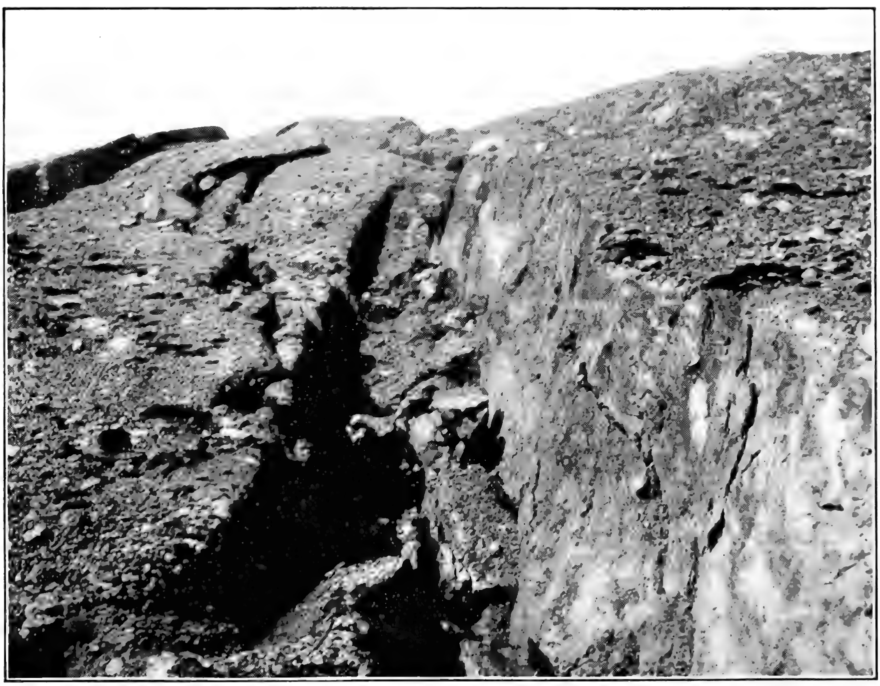


FIGURE 2.—GRABEN FAULT, 30 FEET WIDE (BETWEEN FAULT SCARPS ON LEFT AND IN FOREGROUND), ON GANNETT NUNATAK

FAULTS ON GANNETT NUNATAK

tion was such as to make it possible to interpret the fracturing there as the result of sapping along nearly vertical strata above a stream-cut cliff. On Gannett nunatak, and in the other places, the situation of the faults precludes the possibility of this interpretation, and it is doubtful if even in the case mentioned the interpretation of sapping is the correct one.

Such shattering near a cliff edge would not only cause avalanches during the earthquake, but also prepare the way for future avalanches by opening passageways into the rock. Thus in this respect faulting is an important agent of denudation in favorable localities.

OTHER INSTANCES OF RECENT FAULTING

Similar faults were observed in a number of other places, but nowhere in such numbers as on Gannett nunatak. Recent faults were discovered on the southern slope of mount Tebenkof (strike, north 45 degrees west and north 65 degrees west, true north) and on the ridge south of point Latouche (north 85 degrees east, true north), where, at an elevation of about 1,900 feet, there are a number of faults in a moraine. Several of these have a throw of 3 feet. That the latter can not be due to landslip action is proved by the fact that they cross a valley and extend up the slope of a hill near its middle and several hundred yards away from the nearest steep slope. Recent faults were also observed by Mr Butler and the junior author on a nunatak on the west side of Lucia glacier and on the west spur at the south of Floral pass.

Thus in several widely scattered localities minor faulting was observed, and in a number of places not visited there appeared to be such faults on the mountain slopes; but no case of a single major fault-scarp was observed. The significance of these facts is considered in a later section.

Evidences of Older Changes of Level

EVIDENCE OF OLDER FAULT LINES

Largely on physiographic evidence, Russell assigned to faulting a notable part in the production of the topography of the Yakutat Bay region, and of the mountains up to and including mount Saint Elias, which he describes as a fault block recently uplifted. So far as they go, the tendency of our observations is toward the verification of Russell's generalizations, in so far as the Yakutat Bay region is concerned. The straight mountain front from Yakutat bay southeastward, with its truncated mountain spurs (plate 22, figure 1), has the form of a fault-block mountain front, though we have no facts to prove that it is not an ancient sea cliff, formed before the deposit of the gravels of the Yakutat foreland.

The straight, mountainous east shore of Yakutat bay north of Knight island, also explained as a result of faulting by Russell, certainly suggests this origin by its form.

Geological evidence in the form of abrupt difference in rock structure in a short distance (less than a quarter of a mile) seems to demand a fault line between the Coal series and the older Yakutat series along the mountain face west of Yakutat bay, and between the Yakutat series and the still older Crystalline series along the straight stretch of the lower, or northwest, arm of Russell fiord. One of these inferred lines of ancient faulting is approximately parallel to one of the recent movements.

OLDER ELEVATED SHORELINES

That faults of older date occur in this region, and that the deformation of 1899 is but one of a series of movements, associated with a progressive mountain uplift at present in progress, is suggested by the recognizable

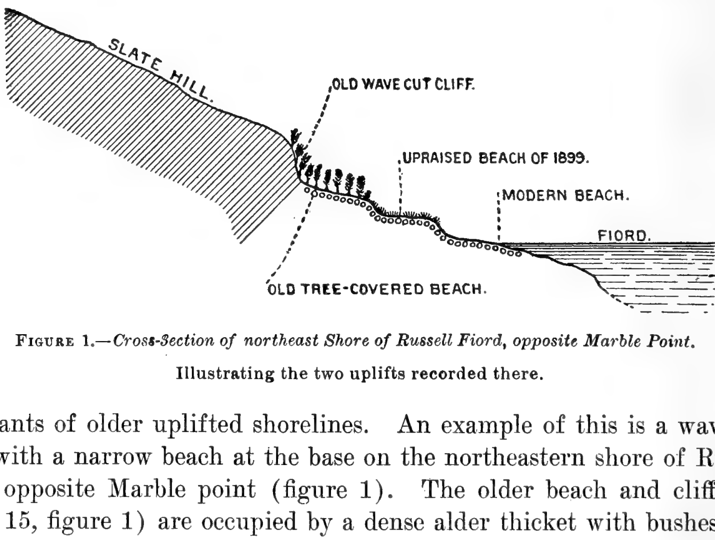


FIGURE 1.—*Cross-Section of northeast Shore of Russell Fiord, opposite Marble Point.*
Illustrating the two uplifts recorded there.

remnants of older uplifted shorelines. An example of this is a wave-cut cliff with a narrow beach at the base on the northeastern shore of Russell fiord opposite Marble point (figure 1). The older beach and cliff (see plate 15, figure 1) are occupied by a dense alder thicket with bushes estimated to be over 25 years old. It rises about 4 feet above the beach which was uplifted in 1899, which is here 9 feet above present sealevel.

On the east side of Yakutat bay, just north of Logan beach, there is an elevated beach with a wave-cut cliff behind it, from which the forest has been partly stripped by the tidal wave (see plate 23 and plate 20, figure 1). One spruce tree, broken by this wave, but still in place on the beach, had 75 rings, proving this uplift to have occurred at least 75 years ago, whereas the recently uplifted strand in front of it bears only annual plants. Both the older and newer uplift on this coast vary decidedly in

FIGURE 1.—MOUNTAIN FACE RISING ABOVE YAKUTAT FORELAND

Head of Russell fiord in distance. Miller lake nearer camera. Fault line A (plate 23) passes along base of mountains. View southeast at elevation of 1,590 feet

FIGURE 2.—SUBMERGED FOREST, LOGAN BEACH, EAST SIDE OF RUSSELL FIORD

Picture taken at mid-tide

MOUNTAIN FACE, ABOVE YAKUTAT FORELAND, AND SUBMERGED FOREST

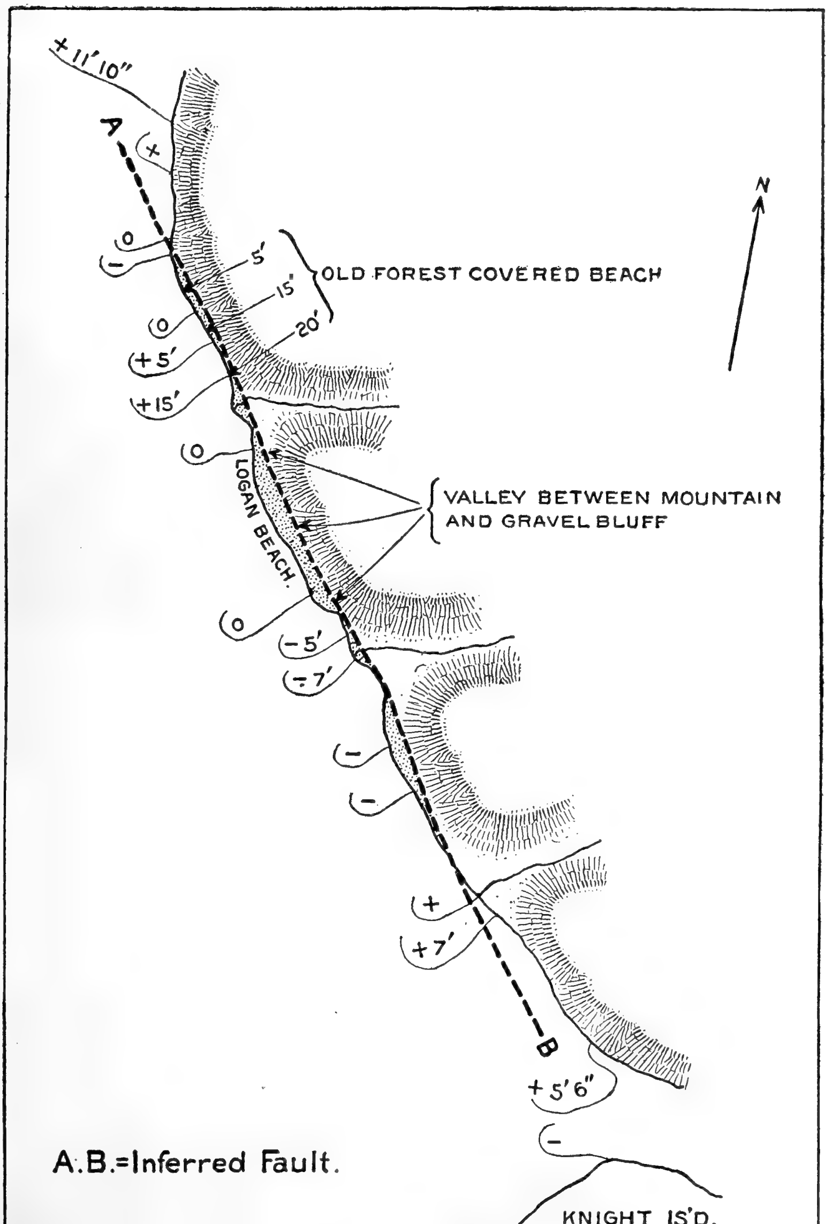


FIGURE 2.—*Sketch Map of east Coast of Yakutat Bay,*
Illustrating the conditions associated with the inferred fault, A-B, along this coast.

amount in a short distance. There are also ancient, forest-covered beaches on Krutoi and Otmeloi islands.

Near the head of Russell fiord there are elevated shorelines about 140 feet above the fiord; but these are believed to be associated with a lake dammed by an ice barrier in lower Russell fiord and Disenchantment bay during a recent advance of the glaciers.

Repeated traverses failed to reveal evidence of higher stands of the sea at levels above those described; but it is to be noted that former greater extension of the glaciers is proved for this region. We have evidence that Hubbard glacier reached down to Haenke island a century ago, and the evidence is clear that all of Nunatak fiord and more than half of Russell fiord have only recently been abandoned by the ice. At an earlier period, but at no very remote time, the entire inlet, clear to the ocean, was occupied by ice. These facts would help to explain the absence of higher shorelines if this deformation has long been in progress.

EVIDENCE OF OLDER DEPRESSIONS

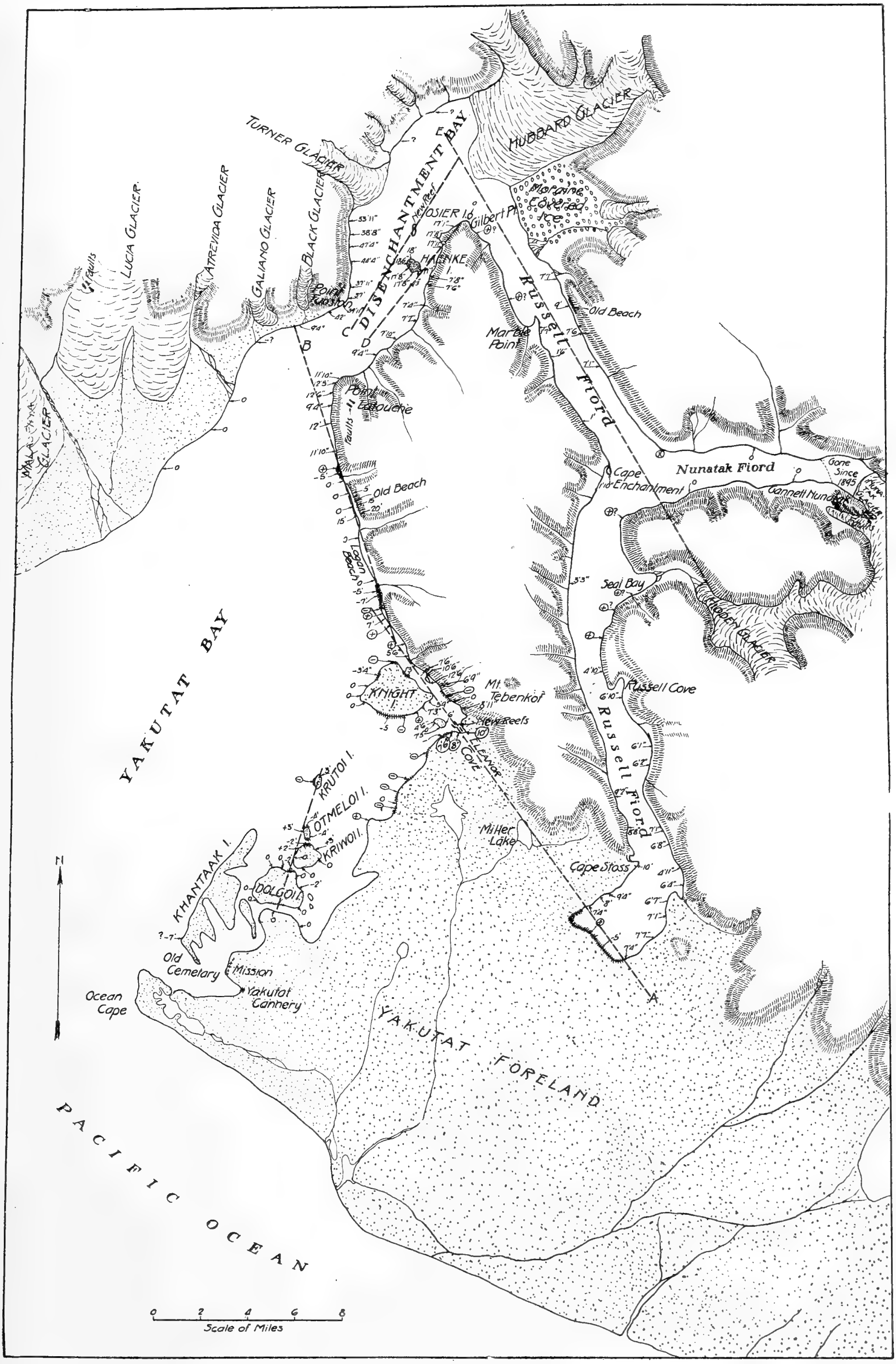
At the head of Russell fiord and at Logan beach (plate 22, figure 2), on the east shore of Yakutat bay, submerged forests appear on the beach between tides. In both cases they occur in places where evidence of uplift in 1899 is absent, and close by, and on the downthrow side of, fault lines inferred from the evidence of the deformed shorelines. In each case evidence of depression in 1899 is found not far away; but the submerged forest at the head of Russell fiord was discovered by Russell in 1891, and therefore this submergence antedates the 1899 deformation.

Statement of Quantitative Observations

METHODS EMPLOYED

Along a coastline upward of 150 miles in length we examined almost every part carefully and selected over one hundred points as suitable places for quantitative measurements. Our method of measuring the change of level necessarily varied with conditions; but wherever possible our measurement is the vertical distance between the highest living and the highest *fixed* dead barnacles, in a place where the latter are well preserved. For obtaining these measurements we used the Locke level and a graduated rod, the greatest elevations being checked by aneroid.

This method, like any other we could devise, was subject to a small error; but, owing to the widespread abundance and excellent preservation of the barnacles on the elevated shoreline, the amount of this error could not be great. Care was taken to select the most favorable sites, and very



SKETCH MAP OF YAKUTAT BAY

Quantitative measurements of deformation of shorelines indicated in feet (′) and inches (″)

often two or more observations were made close together as a check on the one recorded. The possible error is all on the side of conservatism for two reasons. In the first place, along the elevated shoreline occasional barnacles are still living just above the zone of barnacle growth, having been able to survive these six years with an occasional bath of salt water from waves at high tide. Consequently when we took the highest living barnacle, always searched out very carefully, it was often the only living one among many dead forms and several inches above the upper limit of abundant live barnacles. In the second place, the highest dead barnacle actually attached to the rock (and we took account of no others) was often probably not as high as barnacles had grown at the former level of the sea. If the conservative error on both ends could be corrected, we have no doubt that it would often increase the uplift by 6 inches or a foot, but would never diminish the amount stated.

In a very few places where living barnacles were absent from the present shoreline, as along the coast south of Turner glacier, our measurements are between the high-tide mark and the top of the zone of abundant dead barnacles, which was assumed to represent high tide on the old strand. On the elevated beaches we made one or two measurements between parallel lines of driftwood; and two or three measurements were made between the lower limit of land plants on the ancient beaches and the lowest old bushes above it, a possible error of only a foot or two. It should be pointed out that the greater number of our measurements (approximately 80 per cent of them) were made by the conservative method of measurement between highest living and highest dead barnacles, and that all other cases, where another method was necessary, checked well with closely adjacent localities where barnacle observations were possible. The coast south of Turner glacier is an exception, for here barnacles were used only at the upper limit.

Our measurements of depression are much less exact. For these we measured the vertical distance between the base of the lowest tree in place and of the highest on which beach gravels were being piled at the time.

CHANGES OF LEVEL ON THE FORELAND

Taken as a whole, the foreland and its associated islands may be considered as a region of no change of level, though with small areas of slight depression, usually too slight for quantitative measurement. On the west side of Yakutat bay, from opposite point Latouche to the Kwik delta, the shoreline was studied carefully, but no change in level could be detected on the foreland. On the southeast side of the bay, near the mountains, both on Knight island and on the mainland, the changes of

level are very irregular, but on the whole show uplift. A short distance out from the mountain base the uplift ceases, and the same is true at the head of Russell fiord. In all cases, that is on four coasts (both sides of Yakutat bay and Russell fiord) (plate 23), there is a change from an upraised to a depressed or stationary coast in a short distance—within a hundred yards southeast of Knight island and on the southeast shore of the head of Russell fiord and within a mile on the other two shores.

The longest stretch of the foreland coast studied lies between Knight island and Yakutat. Here, both on the shores of the foreland and in the maze of channels between the islands, the usual condition is that of forest coming down to the very water's edge, and therefore giving a very delicate register of change of level. Along most of the coast there has evidently been no change whatsoever; but in two or three places there has been a very slight uplift, and in a number of places the coast has been depressed, especially among the small islands. There is also evidence of older change of level in two or three places, but notably on the northeast end of Krutoi island, where there is a recent uplift of 3 feet, and back of it a beach and wave-cut bluff of much older date with a mature forest growing on it. This older uplift was between 5 and 10 feet.

At and near Yakutat and in the slough near Ocean cape, there is no evidence of change of level. Whether the destroyed cemetery on Khantaak island is evidence of depression or merely the work of the earthquake wave was not determined; but just west of this, on the ocean shore of the island, there is a condition of forest encroached on by present waves which suggests depression of about seven feet. It may, however, represent sea encroachment on the shore, and is therefore considered only tentatively as possible evidence of local depression.

CHANGES OF LEVEL ALONG THE MOUNTAINOUS EAST COAST OF YAKUTAT BAY

The changes of level along this coast are very irregular. Near Knight island the uplift varies from 5 to 12 feet 6 inches, and there are marked variations in short distances. Along the coast north of Knight island to within 4 or 5 miles of point Latouche the average condition is either that of no change of level or else of depression (see plate 23 and figure 2); but where the coast turns eastward, both near Knight island and near point Latouche, uplifted shores begin abruptly, reaching a maximum of 10 feet near Knight island on the mainland, and of 12 feet 6 inches near point Latouche.

Along the straight stretch of coast between the uplifted parts there is a general condition of gravel foreland forming a narrow strip between the mountains and the sea (figure 2). In one part, however, just north of Logan beach, the mountains come down close to the sea, and here for a short distance there is a recently elevated shoreline 15 feet above present sealevel, but descending abruptly northward, and disappearing in less than a half mile. Back of it is the older, spruce-covered beach already described, which descends northward more than 2 miles before being lost. As shown in a later section, these phenomena are believed to be related to a fault line close by the mountain base.

CHANGES OF LEVEL IN DISENCHANTMENT BAY

At point Latouche the uplifted shores are 11 to 12 feet above present sealevel, but perceptibly decline northward, for most of the distance between point Latouche and Haenke island (on the east side) being between 7 and 8 feet. At Haenke island, however, the raised shorelines are 18 or 19 feet, and this marked uplift abruptly appears on the peninsula northeast of Haenke island (see plate 13 and plate 17, figure 2), and extends nearly to Gilbert point, where it disappears equally abruptly. Within a mile, at Gilbert point, there is a change from no uplift on and near Osier island to 17 feet 1 inch just southwest of it. It is in this region of marked uplift that the new reefs appear just north of Haenke island.

On the west shore of Disenchantment bay the first rock cliff south of Turner glacier (a quarter of a mile from the glacier) shows an uplift of 33 feet 11 inches; and this remarkable shoreline, the most perfect as well as the highest in the region (see plate 14, figure 2; plate 16, figure 1, and plate 18, figure 1), attains an elevation of 47 feet 4 inches within a distance of a mile and a half. Just below point Funston the elevation is 42 feet, and south of that it rapidly descends. No accurate quantitative measurements were possible in this region of disappearance, but the uplift evidently extends to the Black glacier alluvial fan, where on the north side it is estimated to be about 30 feet, and on the south side, a little over a quarter of a mile away, 9 feet. South of this no evidence of uplift was found; but on the alluvial fan of Galiano glacier, a mile and a half southwest, there is indication of slight subsidence, and beyond that no reason for inferring any change of level.

From these facts it is evident that the shores of Disenchantment bay have been greatly uplifted (the highest in the fiord), and that they have been differentially deformed. While the changes in amount of uplift occur within short distances here, as in other parts of the fiord, they are

not traceable to a single sharp break, but are apparently the result of decided change taking place in a narrow zone.

It would be interesting to know what effect a 34-foot uplift had on the crevassed front of Turner glacier, for there is evidence of this great elevation up to the very edge of the ice. Gilbert suggests that the front of this glacier is floating, and if this is true the effects of uplift would have been more destructive than if the ice rested on the bed of the fiord. We were unable to determine what effect the uplift had; but it is noteworthy that the form of the ice-front has been materially changed since Gilbert photographed it in 1899.

CHANGES OF LEVEL IN THE NORTHWEST ARM OF RUSSELL FIORD

The northeastern shore of this fiord, from the Hubbard glacier to Nunatak fiord, shows uniformly an uplift of considerable amount (plate 15, figures 1 and 2); but the conditions for accurate measurement of the uplift were not usually present on the friable slate rock and extensive beaches which constitute this shore. Four good observations were secured, one of them on the beach (7 feet 7 inches), the other three on barnacles on the rock (plate 17, figure 1), giving measurements of 7 feet 1 inch, 7 feet 6 inches, and 9 feet. It is along this coast that an older beach, covered with mature alders, was discovered (see figure 1).

On the southwest shore, on the other hand, although the rocks are very favorable for preservation of barnacles, we nowhere found evidence, either of a physiographic or a biologic nature, of uplift of over 2 feet. On most of the coast the evidence is wholly negative, but at four points we found dead barnacles on a slightly elevated bench from 1 foot to 1 foot 10 inches above the highest living barnacles. The evidence is convincing that there is a marked difference in the uplift on the two sides of this narrow, straight stretch of fiord.

NUNATAK FIORD

We have already described the conditions on the southern shore of Nunatak fiord, where there is no clear proof of change of level, but a possibility of an uplift of a foot or less. The northern shore of the fiord likewise gave no proof of change of level; but this coast is wholly beach and alluvial fan on which a moderate uplift might easily be indistinguishable. The difficulty of discovering an elevated shoreline in this part of the fiord is increased by the fact that the recession of the glacier has been so recent that abundant vegetation has not advanced far up the fiord, and this aid to detection of uplifted beaches is therefore absent. However, the fact that no evidence of change of level could be discovered in this fiord, while

not proving entire absence of change, is believed to demonstrate very slight, if any, change.

CHANGES OF LEVEL IN THE SOUTH ARM OF RUSSELL FIORD

At cape Enchantment there is evidently an uplift of less than 2 feet, and several miles south of this, opposite Seal bay, of 3 feet 3 inches. Between these two points there is a succession of slightly elevated beaches and fans; but on the east side of the fiord, while a slight uplift is indicated, we could got no definite measurement until a point was reached 2 or 3 miles south of Seal bay. Conditions along this eastern coast are perfect for the preservation of evidence of uplift, and our failure to find definite evidence convinces us that the uplift here was at best very slight. Quite abruptly, however, just north of Russell cove, a wave-cut bench rises, and on it we found dead barnacles 4 feet 10 inches above the highest living ones. South of this the bench slowly rises, reaching an elevation of 9 or 10 feet on the west side and 7 or 8 feet on the east side of the fiord (plate 14, figure 1). At the very head of the inlet, in the fist-shaped area in the foreland, there is a change in a very short distance on both sides of the bay from an uplift of 7 feet 4 inches to a depression (plate 18, figure 2).

Interpretation of Observations

IN GENERAL

Our observations lead us to the conclusion that here, in a non-volcanic region, the land is still rising. Moreover, there is definite evidence that earlier movements have preceded that of 1899. How widespread the effects of this last movement were on the Pacific coast is not yet known; but the destruction known to have occurred in September, 1899, at the front of the Muir glacier, 140 miles away, suggests the possibility of its extension this far, and observations in that region will be awaited with interest. At Dundas bay, near the entrance to Glacier bay, we landed for a few hours, but found no evidence of change of level; and there was none at Sitka. On our way down the Inside passage we looked for evidence of change of level, but without success, excepting in the narrow passage just north of Ketchikan, several hundred miles farther southeast, where there has been a recent uplift of unknown date and amount, the evidence of which is visible from the steamer.

In the region of our detailed studies it is evident that the uplift was differential and that the movements were complex, resulting in a distinct deformation of the coastline and bordering land. The exact nature of

these differential movements is not certain in all cases, though some conclusions regarding them seem clear and well founded.

MOUNTAIN-FRONT FAULT

That there is a zone of narrow width, just outside the mountain base, where uplift is replaced by either depression or no change, is clearly shown at four points. This suggests the presence of a fault line near the mountain base. If such a line is projected (see fault line A, plate 23) it passes through three of the areas where uplift is replaced by depression or no change, but would need to be bent slightly to reach the fourth at the head of Yakutat bay on the west side. From this evidence a fault line is inferred along the face of the mountain from the head of Russell fiord to Knight island.

Additional reason for suspecting an older fault here is found in the topography already described—a straight mountain front with truncated spurs reaching out to nearly the same line (plate 22, figure 1). Along this line, northeast of Knight island, there is also an unusual development of avalanches. Moreover, the amount of uplift along it varies greatly, as it naturally would along a fault with the downthrow side dragged upward, and with the fault line not a single break but a complex of parallel fractures, as seems to have been the case in this region, where the change across the fault line is not an abrupt scarp, but occupies a zone of some width. The statement of Ensign Miller that trees are destroyed on the east and west side of Miller lake is interesting, since this is exactly where we place our fault line on entirely independent evidence.

Harmonious with the interpretation placed on the facts in this region is the appearance of the four small islands east of Knight island, exactly where the inferred fault is believed to pass, and with their long axes parallel to the fault line. We do not place this fault line outside the zone of uplift because it is believed that some of the upraised coast near and on Knight island is due to updrag on the downthrow side.

POSSIBLE MINOR FAULT SOUTHWEST OF KNIGHT ISLAND

There is the possibility of a second fault of minor character along the islands between Knight island and Yakutat (see fault line, plate 23). The evidence of this is not convincing, and this fault is proposed solely on the basis of the fact that there is a rather remarkable linear arrangement of uplifted and depressed areas in the midst of a region which, in general, shows no sign of change in level. The fact that earlier changes of level are recorded in these same places by older uplifted beaches, and that similar shorelines were not discovered elsewhere in the foreland, is

a part of the evidence on which a fault line is inferred with some doubt along the axes of these islands.

FAULT ALONG EAST SHORE OF YAKUTAT BAY

Much clearer evidence of a fault line exists along the mountainous eastern shore of Yakutat bay (see unlettered fault line B, plate 23). Here the mountain front is straight, steep, and has spurs truncated along a straight line. The mountain face is scarred by numerous avalanches, and the shores at its base were washed by the most destructive tidal wave recorded in the region (plate 20, figure 1). For much more than half its length this shore shows no elevated strands; but they begin where the coast bends away from the straight line on both the north and south end; and near the middle, where the mountain slopes come down close to the sea, there is an upraised ancient beach and, parallel to it, an uplift belonging to the 1899 series (see figure 2).

We are able to suggest no other explanation for the phenomena recorded here than that of a fault close to the mountain base, lifting the hard rock of the mountains, but not raising the gravel forelands which skirt most of this straight coast. In this connection it is notable that behind the broadest part of the narrow foreland, at Logan beach, there is a valley between the foreland and the mountains, whose formation by earlier faulting is easy to understand, but difficult of explanation in any other way. That the earthquake shock was violent here is proved by the fact that a gold miner's log cabin on the gravel bluff above Logan beach was partially demolished, unroofed, and thrown part way off of its foundations during the earthquake of 1899.

We are not absolutely certain whether to correlate this fault with the one inferred farther southeast along the mountain front (plate 23, fault A), which it intersects at a low angle, assuming the two to be connected by a slight bend, or whether to consider it a separate and distinct fault. The later interpretation is placed on the map, but we have no evidence to prove this interpretation as opposed to that of a single continuous, slightly curved fault line. It is a notable fact that this fault line, extended, strikes the western side of the head of Yakutat bay exactly at the point where the great uplift south of Turner glacier dies out.

FAULTING ALONG DISENCHANTMENT BAY

The great uplift (reaching over 47 feet) on the west shore of Disenchantment bay; the lesser, but still great (18 to 19 feet), uplift on Haenke island and the shore of the peninsula north of it; and the moderate uplift (7 to 9 feet) along most of the east shore of Disenchantment

bay seem to demand at least two lines of faulting. One of these (see line C, plate 23) is inferred between Haenke island and the west shore, one (line D, plate 23) between Haenke island and the east shore. No other evidence of these inferred faults was discovered than the remarkable differences in uplift in short distances. The rapid descent of the elevated shoreline from 17 feet to no change at Gilbert point is believed to be related to the fault line along the northwest arm of Russell fiord.

FAULT LINE IN NORTHWEST ARM OF RUSSELL FIORD

It has already been shown that geological structure indicates the existence of an older line of faulting along this straight reach; that an uplifted beach of older date exists on the northeast shore, but none was discovered on the southwest shore; and that the uplift of 1899 upraised the northeast shore from 7 to 9 feet and the southwest shore nowhere more than 1 foot 10 inches, so far as we could see. These facts point clearly to a fault line along the axis of this part of the fiord (see fault line E, plate 23).

Nunatak fiord gives us no proof of change of level, though the nunatak at its head is badly fractured.

SOUTH ARM OF RUSSELL FIORD

From a region of very slight uplift near cape Enchantment, and a possible slight uplift on the opposite shore, there is a rise in the elevated shore line to a maximum of 10 feet near the head of the inlet, where in a short distance the uplift is abruptly replaced by depression on the foreland along the line of the inferred mountain-front fault (line A, plate 23). There is no evidence of faulting along the axis of this part of the fiord; and no proof of an earlier uplift was discovered.

MINOR FAULTING

In addition to the major lines of faulting which we have inferred, evidence exists at several widely scattered points proving a minor shattering of the crust, as stated in the preceding paragraphs. These places have in no case been found along the lines of inferred major faults, but in all cases where observed they appear to be due to a minor shattering in the larger uplifted blocks. The fact that no uplifted shorelines occur near the shattered Gannett nunatak is not significant, since the present coast of the nunatak was more nearly inclosed by ice in 1899, and a few years previous to that (in 1891) was completely inclosed; so that by 1899 there had not been opportunity for the development of a shoreline on the nunatak.

FOLDING VERSUS FAULTING

Both in the field and since our return we have attempted to place the interpretation of folding on the phenomena of deformation described, but

without success. Opposed to folding are four significant facts which seem to eliminate it as an hypothesis. In the first place, the lines of deformation extend in too many directions. In the second place, the zones of gradation between areas of different degrees of deformation are exceedingly narrow, while the intervening areas of uplift are very broad. In the third place, the minor faulting proves dislocation in parts of the region. Finally, faulting is proved by the series of earthquakes and their destructive avalanches and water waves.

NATURE OF THE DEFORMATION

Briefly summarizing the inferences which the facts seem to warrant, we conclude that in 1899 there was a renewal of mountain growth, uplifting that part of the mountain front bordering the Yakutat bay inlet to different amounts—7 to 10 feet on the southeast side of the bay and 40 to 47 feet on the northwest side. This uplift occurred all within a little over two weeks and mainly on a single day (September 10). It was complicated by movements along secondary fault lines, which produced at least three (and perhaps more) distinct major blocks, as follows: (1) The area between fault lines A, B, C, and E (plate 23), including all the peninsula and a part of the mountains east of the south arm of Russell fiord to an unknown distance toward the southeast; (2) a block west of fault line E (plate 23), extending westward an unknown distance from the west shore of Disenchantment bay; (3) a block extending northeastward for an unknown distance from the northeast shore of the northwest arm of Russell fiord. The first and largest of these blocks, that including the peninsula, is apparently tilted upward toward the southwest.

Accompanying this faulting was a minor fracturing apparently due to local adjustments in the tilted blocks. Doubtless this minor fracturing is much more common than our observations indicate, for it was discovered in more than half of our expeditions into the interior when we went out of the valleys away from the seacoast.

TOPOGRAPHIC SIGNIFICANCE

That this faulting may be part of an important process by which the main lineaments of topography in this region were developed is evident. The straight mountain front, the straight mountainous eastern shore of Yakutat bay, and the straight northwest arm of Russell fiord all bear evidence of faulting during this recent period of uplift, and the evidence seems to demand the presence of two fault lines along Disenchantment bay. How far this process of faulting can be applied in explanation of the initial outlining of the fiords is not certain from any facts we could

gather; but of one thing we are certain: In spite of the parallelism of the fault lines to several reaches of the fiord, and in spite of their possible importance in determining the main lineaments of the valleys, the present depth and form of the fiords are assignable not to faulting but to glacial erosion. The evidence of this is clear and convincing, but the statement of it can not be made in this paper.*

Comparison with Other historic Uplifts

While there are many evidences of changes in level during recent geological time, in widely separated localities, some of a slow secular nature still in progress and involving extensive areas, some evidently abrupt and involving smaller areas, the great majority of these give us no clue either to the time or nature of occurrence or to the amount of uplift at a given period.

Some instances are fairly definite in these respects, and some locate the period of uplift and determine its amount with exactness. A preliminary examination of the literature fails to find a single instance in which an uplift approximating in amount that of the Yakutat Bay region, in its maximum, is described as having occurred at a single period of disturbance. Compared with the historic changes of level associated with definite earthquakes, the Yakutat Bay deformation therefore stands conspicuous. It is apparently the greatest historical change of level (47 feet 4 inches at the maximum); it combines the various classes of evidence—beaches, benches, sea caves, marine animals, human testimony, as in South America (1822, 1835, 1839); new reefs, accompanying faulting, as in New Zealand (1855); combination of elevation and depression, as in India (1811); and it adds the new types of evidence of dissected alluvial fans and uplifted till shorelines, besides furnishing the most complete interrelated evidence of all sorts in practical agreement.

* See Tarr and Martin: Bull. Amer. Geog. Soc., vol. xxxviii, 1906, pp. 145-167.

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CARBONIFEROUS OF THE APPALACHIAN BASIN*

BY JOHN J. STEVENSON

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CONTENTS

INTRODUCTION

The Coal Measures above the Pottsville have been grouped in various ways by those who have studied the Appalachian basin.

* The earlier papers of this series are in this Bulletin, volume 14, pages 15-96; volume 15, pages 37-210. The writer desires to acknowledge his obligations to Dr I. C. White, Mr David White, and Mr E. V. d'Invilliers, who have given him information and valuable criticisms without reserve. It must be understood, however, that these observers are in no wise committed to the conclusions offered by the writer.

In the early reports on the geological survey of Pennsylvania Professor Henry D. Rogers used a numerical scale to designate the formations, the Pottsville being XII and the Coal Measures above being XIII; but in the fourth report he divided Formation XIII into the Allegheny and Monongahela series, drawing the line between them at the lowest rock bed seen at Pittsburg, or nearly at the place of the Ames limestone. In the next year he abandoned the geographical terms, using only XIII and designating the lower coals by letters.*

The numerical method was adopted in Virginia by Professor William B. Rogers, the Pottsville being designated by 12 in his second report. Two years later he divided the measures into the Lower and the Upper Coal series, separated by a considerable thickness of barren measures, and in his fifth report he gives

Lower Coal group, or Formation XIII;
Lower shale and sandstone group, or Formation XIV;
Upper Coal group, or Formation XV;

the Mahoning sandstone being included in the Lower group.†

In 1856 Professor J. P. Lesley offered this grouping:

Barren measures,
Upper series,
Barren measures,
Mahoning sandstone,
Lower series,

with the Pittsburg coal as the highest member of Number 3 and the upper limit of Number 2 indefinite.‡

Professor Rogers's final report of the geology of Pennsylvania appeared in 1858 and contained this arrangement:

Upper Barren Waynesburg group and Pittsburg coal and limestone	Greene County group.
Lower Barren measures Mahoning sandstone	Middle or Barren group.
Freeport group Freeport sandstone Clarion group	Lower group.

The plane between the Allegheny and Monongahela of the previous

* H. D. Rogers: Second Ann. Rept. Geol. Explor. of Pennsylvania, p. 71; Third Rept., p. 62; Fourth Rept., p. 150.

† W. B. Rogers: Rept. Geol. Virginia for 1838, p. 84; Rept. for 1839, p. 98; Rept. for 1840, p. 76 et seq.

‡ J. P. Lesley: Manual of Coal and its Topography, pp. 94, 116.

arrangement had been placed almost midway in the Lower Barren measures.*

In 1870 Professor John S. Newberry divided the Ohio Coal Measures into Lower and Upper, including in the former all beds below the Pittsburg coal to practically the bottom of the Pottsville. Professor Edward Orton adopted this classification in his elaborate discussion of the Ohio coals, published in 1884.†

In the same year Stevenson employed the terms Lower and Upper for the Coal Measures of northern West Virginia, drawing the plane of separation just under the Pittsburg coal bed, but including only rocks above the Pottsville. In 1872 he grouped the deposits into

Upper Barren group,
Upper Coal group,
Lower Barren group,
Lower Coal group,

the last two being equivalent to XIII and XIV of W. B. Rogers and the first two equivalent to the higher groups of H. D. Rogers, as published in the final report.‡

Toward the end of 1875, in the first of the Pennsylvania reports, Mr Franklin Platt divided the Pennsylvania Coal Measures into

Upper Barren measures;
Monongahela, from Washington coal bed to Pittsburg coal bed;
Conemaugh, bottom of Pittsburg to bottom of Mahoning sand;
Allegheny, bottom of Mahoning sandstone to top of Pottsville;

using names originally employed by Professor Rogers, but not in the same sense.§

In 1876 Stevenson used the same grouping as in 1872, with a slight change in nomenclature, thus:

Upper Barren series { Greene County group. Washington County group.
Upper Productive series.
Lower Barren series.
Lower Productive series.||

In the next year, Mr Platt modified his classification materially, his new grouping being

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* H. D. Rogers: Geology of Pennsylvania, vol. ii, pp. 477, 500, 503.

† J. S. Newberry: Rep. Prog. Ohio Survey for 1870, p. 15.

‡ J. J. Stevenson: Regents' Report of West Virginia University for 1870, p. 47; Trans. Am. Phil. Soc., vol. xv, p. 15 et seq.

§ F. Platt: Second Geol. Survey of Pennsylvania, Report H, p. 8.

|| J. J. Stevenson: Report K, pp. 34 et seq.

I. Monongahela River system.
  a. Greene County group of Upper Barren measures.
  b. Washington County group of Upper Barren measures.
  c. Upper Productive Coal Measures.
II. Allegheny River system.
  a. Lower Barren measures.
  b. Mahoning sandstone.
  c. Lower Productive Coal Measures.

the plane between the two systems being drawn at the bottom of the Pittsburg coal bed.* But the geographical terms were abandoned quickly, and in later volumes of the reports the terms Upper and Lower barrens, Upper and Lower Productive Coal Measures were used instead, the Mahoning sandstone in most of the reports being included in the Lower Productive Coal Measures.

In 1891 Doctor I. C. White introduced the term Dunkard to designate the Upper Barren measures, the Greene and Washington County groups of Pennsylvania, Report K, and at the same time limited the term Monongahela to the Upper Productive Coal Measures.†

The synonymy may be given as follows in ascending order:

Coal Measures, XIII of H. D. and W. B. Rogers

Allegheny .... F. Platt, 1875.	Allegheny of H. D. Rogers in part; XIII, Lower Coal group of W. B. Rogers less the Mahoning sandstone; Lower series of Lesley; Lower productive series of Stevenson less the Mahoning; Lower Coal Measures of Ohio in part; Lower group of H. D. Rogers.
Conemaugh .... F. Platt, 1875.	Barren measures of Lesley plus the Mahoning sandstone; Lower shale and sandstone group of W. B. Rogers plus the Mahoning; Lower Barren series of Stevenson plus the Mahoning; Lower Coal Measures of Ohio, upper part; Middle group of H. D. Rogers.
Monongahela .... I. C. White, 1891.	Middle portion of Monongahela of H. D. Rogers; Lower portion of Monongahela of F. Platt; Upper productive series of Stevenson; lower portion of Upper series of Lesley; in part XV, Upper Coal group of W. B. Rogers; lower portion of Upper Coal Measures of Newberry; lower division of Greene County group of H. D. Rogers.

* F. Platt: Report H H, pp. xxiii, xxiv.
† I. C. White: U. S. Geol. Survey Bulletin no. 65, pp. 20, 43.

Dunkard .... I. C. White, 1891.	Upper Barren series of Stevenson; upper part of Greene County group of H. D. Rogers; upper part of Upper Coal Measures of Newberry; upper part of XV of W. B. Rogers.

In the description of the several formations, the names here given will be employed as limited by Franklin Platt and I. C. White.

Allegheny Formation

CORRELATION

The plane of separation between the Pottsville and the Allegheny in the bituminous area is marked on top of the Homewood sandstone, but only approximately, for, as will be seen, that sandstone is replaced more or less by shale in extensive spaces, while in others it is continuous with sandstone extending upward even into the Conemaugh. A more convenient base is the Brookville coal bed, belonging a few feet above the Homewood in its normal condition. The Allegheny is paleontologically as well as stratigraphically distinct from the underlying Pottsville; for, although the fauna exhibits comparatively little change, there is, as shown by Mr David White, for a great part of the field a very marked difference in the flora.

The Allegheny area is much smaller than that of the Pottsville. It becomes narrow in southern West Virginia and northeastern Kentucky. The present condition of our knowledge makes impossible any positive conclusions respecting its extent in southeastern Kentucky and southwestern Virginia, though reconnaissance work in the former state suffices to show that Allegheny coal beds are present there. It is possible that the formation reaches into the northeastern corner of the Tennessee coal field. Uncertainty prevails respecting the correlation of beds in the anthracite areas of Pennsylvania, which will be considered apart after the description of the Conemaugh.

Though comparatively thin, at most little more than 300 feet, the Allegheny contains a large number of elements, most of which are persistent for long distances on both sides of the basin, though practically all becomes unidentifiable in much of the broad interior, where throughout the Coal Measures the coal beds and limestones disappear or become indefinite and there remains only detrital matter of variable character. The important elements are:

Upper Freeport coal bed.
Upper Freeport limestone.
Butler sandstone.
Lower Freeport coal bed.

Lower Freeport limestone.
Freeport sandstone.
Upper Kittanning coal bed.
Johnstown cement limestone.
Middle Kittanning coal bed.
Lower Kittanning coal bed.
Vanport limestone.
Clarion coal bed.
Clarion sandstone.
Putnam Hill limestone.
Brookville coal bed.

The Upper Freeport coal bed... J. P. Lesley, 1856. In Pennsylvania, Kelly of Broad Top, E of Rogers and Lesley, Upper Freeport of authors; in Ohio, 6 and Big vein of Columbiana, Cambridge of Guernsey, Alexander of Muskingum, Stallsmith, Norris, Bayleys run of Hocking valley, 7 of Tuscarawas; in West Virginia, Upper Freeport, Mason; in Maryland, Upper Freeport; in Kentucky, Coal 9.

This coal bed is present in nearly every county of Pennsylvania where its place is reached and it is important economically in extensive areas. It is traceable in most of the Ohio counties as well as along the eastern outcrop in West Virginia, where also it is frequently important. It is irregular in Kentucky and is wanting or very thin in much of the central region within West Virginia and Kentucky. Its irregularity along the outcrop is due in some measure to erosion during deposit of the Mahoning sandstone, but there are considerable areas in which the coal never existed. The bed is broken in many places by numerous partings, so as to be a thick mass of coal and shale. In some localities it is associated with a flint clay of good quality.

The Upper Freeport limestone.. H. D. Rogers. In Pennsylvania, Upper Freeport; in Ohio, Upper Freeport, "White" of Columbiana, Shawnee of Hocking valley; in Kentucky, First Fossiliferous.

This limestone is of somewhat uncertain occurrence in portions of Pennsylvania, but in a general way is one of the best marked strata in the section. In southern Ohio and in Kentucky it is so persistent as to be a notable stratigraphical guide, but in West Virginia it seems to disappear quickly south from the Pennsylvania line. Ordinarily it is non-fossiliferous, though occasionally showing some forms presumably of fresh-water types; but Professor Crandall describes it in Kentucky as carrying a characteristic Carboniferous fauna and terms it the First Fossiliferous limestone.

The Butler sandstone of I. C. White, Upper Freeport sandstone of authors, is, like most of the sandstones, somewhat indefinite; but one finds very frequently in the interval between the Freeport coal beds a sandstone, sometimes very thin, at others filling the whole interval. There is no regularity in the occurrence of these sandstones.

The Lower Freeport coal bed... J. P. Lesley, 1856.	In Pennsylvania, Lower Freeport, Middle Freeport, D. D′; in Ohio, Roger and Shaft of Jefferson, 6*a* of central counties, Black, Fowler, Juniper, Frank of Hocking valley, Hatcher, Waterloo of Lawrence; in Kentucky, Coal 8; in West Virginia, Lower Freeport.

This is almost as persistent in Pennsylvania, Ohio, and Kentucky as the Upper Freeport, but is less frequently of economic importance. It shows abrupt and extreme variations in thickness as well as quality and occasionally carries on top a thick deposit of impure cannel. It yields excellent coal in Jefferson county of Ohio, but in the greater part of that state it is worthless. Locally it is valuable in southern Ohio, but is insignificant in both Kentucky and West Virginia.

The Lower Freeport limestone.. H. D. Rogers.	In Pennsylvania, Lower and Middle Freeport; in Ohio, Norris and Snowfork of Hocking valley; apparently wanting in Kentucky and West Virginia.

In general features this resembles the Upper Freeport limestone. In the eastern basin of Pennsylvania it extends farther north than any other limestone, but its distribution throughout is very uncertain. Like the Upper Freeport, it varies in purity, yielding at times fine lime, but often is wholly worthless. Fossils are rare and those which do occur are thought to be of fresh-water types.

The Freeport sandstone of H. D. Rogers is as irregular and indefinite as the Butler sandstone, but in most localities a sandy shale or sandstone is present within the interval between the Lower Freeport and Upper Kittanning coal beds. This interval shows some interesting variations in Clarion and Armstrong counties and elsewhere in western Pennsylvania.

The Upper Kittanning coal bed. F. Platt, 1877.	In Pennsylvania, Currie of north Butler, Darlington of south Butler; rarely present in Ohio and Kentucky; indefinite in West Virginia.

This is a widely persistent though very variable bed in Pennsylvania, but it disappears in the western part of that state to reappear somewhat rarely in Ohio. It quickly becomes indefinite in West Virginia and can not be recognized with certainty in the Kentucky sections.

The Johnstown cement limestone of W. G. Platt, Upper Kittanning of the Ligonier Valley report, is confined practically to the first and second bituminous basins of Pennsylvania, being found in only two or possibly three counties west from Chestnut hill in that state. It was confounded for a long time with the Vanport limestone, an error which led to confusion in those basins, where the lower limestone is wanting. It is nonfossiliferous.

The Middle Kittanning coal bed. H. M. Chance, 1879. In Pennsylvania, Middle Kittanning, Kittanning, Lower Kittanning of Ligonier valley, Darlington of Mercer and Lawrence; in southern Ohio, No. 6, "Great vein," Nelsonville, Hocking valley, Sheridan, etcetera; in Kentucky, Coal 7.

For the most part this is unimportant in Pennsylvania, though it is widespread and occasionally, like the Upper Kittanning and the Lower Freeport, carries a deposit of cannel which locally is of some importance; but in Ohio it attains vast importance within the Hocking Valley coal field. In much of Ohio it is roofed by a black shale carrying a rich marine fauna. The overlying shale has yielded an abundant flora in western Pennsylvania.

The Lower Kittanning coal bed. F. Platt, 1877. In Pennsylvania, Kittanning, Lower Kittanning, Barnett of Broad Top, Clarion of Ligonier valley, Dagus of McKean and Elk; in Ohio, Leetonia, "Clay vein," "Creek vein" No. 5 of Columbiana and Jefferson, Newcastle in southern Ohio; in Kentucky, Coal 6; in West Virginia, Kittanning; Kittanning of Lesley, 1856.

This coal bed is equally persistent with the Upper Freeport and shows similar variations in commercial importance. It is best on the eastern side of the basin, but occasionally it is good enough and thick enough in Ohio to be mined; it is unimportant for the most part in Kentucky. The interval between Middle and Lower Kittanning often disappears in Maryland and eastern West Virginia, so that both beds can be mined as one. The underlying clay is of great industrial importance in western Pennsylvania and in much of Ohio. The interval between Upper Freeport and Lower Kittanning shows no abrupt variations in most of Pennsylvania, though within the same area the intervals between intervening beds exhibit perplexing variations. The interval between the Lower Kittanning and the Vanport limestone below is one of the most variable in the whole section. When large, it often contains the Kittanning sandstone, whose changes in character are as marked as those of the Freeport and Butler.

The Vanport limestone......... I. C. White, 1878.	In Pennsylvania, Ferriferous, Vanport; in Ohio, Ferriferous, Baird, Coshocton marble; in Kentucky, Ferriferous; in West Virginia, apparently wanting.

This is in some respects the most remarkable member of the formation; it has not been observed in the first and second bituminous basins of Pennsylvania, but a limestone of similar character has been reported from the first basin southward in Maryland, which, however, may prove to be at the Putnam Hill horizon. This bed has been observed only at one locality in the area immediately west from Chestnut Hill, and there is much room for doubt respecting its existence in the counties south from the Ohio and Kiskiminetas except near the former river toward the West Virginia line; but north from those rivers it is persistent almost to the northern outcrop and to the Ohio line, becoming somewhat irregular toward the north, where it is replaced sometimes by cherty limestone or sandstone and seems to project, finger like, northward from the main mass. It practically disappears within a few miles west from the Ohio line, though it has been recognized by Professor Orton at several places beyond. In Pennsylvania it usually underlies an iron ore which in the earlier days was the source of supply for many furnaces. It reappears in central Ohio as the Black marble of Coshoction county, and thence southward it is followed easily as the Baird ore and limestone, to which E. B. Andrews applied the name Ferriferous limestone, but without any reference to the Pennsylvania bed. It is persistent southward in Kentucky into Elliott county and appears occasionally in Morgan county beyond; but eastwardly it disappears in Boyd and Lawrence counties before reaching the West Virginia line. It belongs chiefly to the western side of the basin. Within Pennsylvania and northern Ohio it carries a marine fauna, but in southern Ohio and Kentucky it seems to be non-fossiliferous.

The Clarion coal bed of H. D. Rogers is a double bed, as was demonstrated by Doctor H. M. Chance, but the splits are recognizable as such in a very small area, so that they have received distinct names. The upper split is:

The Scrubgrass coal bed....... I. C. White, 1879.	Sulphur, Ferriferous, Upper Clarion, Canfield, at various localities in Pennsylvania and Ohio.

This bed occurs in western Pennsylvania and in much of Ohio directly below the Vanport limestone or separated from it by at most 10 feet. It is of uncertain occurrence and rarely is thick enough to be mined even for local supply.

The Clarion coal bed proper, 15 to 20 feet lower, is the limestone vein of Vinton county, Ohio, and is the more persistent bed, though not often of economic importance. In the first and second bituminous basins of Pennsylvania it is wanting south from the Conemaugh river and westward from the Chestnut Hill anticline; it disappears quickly in West Virginia; but it may be represented on the Kanawha river and southwestward by the coal seen occasionally above the Black flint. This bed becomes very indefinite in southern Ohio and occurs so rarely in Kentucky that it is not recognized in the generalized section. It is quite likely that at not a few localities the Brookville has been mistaken for this bed.

The Clarion sandstone, Hecla of southern Ohio, is present in many places between the Clarion and Brookville coal beds and is rather more persistent than the other sandstones; yet it is frequently replaced in part or in whole by shale, at times argillaceous. Along the southeasterly outcrop from Randolph county, West Virginia, to the Kentucky line the whole space from the Brookville coal bed to the Upper Freeport is filled with sandstone, interrupted only by coal beds and thin shales; but this, in part the Charleston sandstone of Mr M. R. Campbell, is for the most part coarse and evidently marks proximity to a shoreline, as it extends westwardly for only a few miles, changing gradually into shale and finer sandstone. A similar condition is revealed by oil-well records in Ohio, Marshall, Wetzel, and Tyler counties of West Virginia, along the central portion of the basin. Whether or not the sandstone areas of those counties are one can not be asserted, but the records are so numerous as to suggest continuity of the deposit. The irregularity in outline of the sandstone area is as irregular as that of open sand in the main oil-sands of Pennsylvania. The change from hard sandstone to fine shale and again to sandstone takes place at times within a few rods.

The Putnam Hill limestone..... **E. B. Andrews, 1870.**	**Gray limestone of northern Ohio; apparently absent in Pennsylvania and Kentucky; Kanawha black flint of West Virginia.**

Within Pennsylvania and the greater part of West Virginia, as well as in Kentucky, the Brookville coal bed underlies coarse or fine detrital material from the land; but in northern Ohio, at a short distance west from the Pennsylvania line, a new element appears in the section, which is persistent thence almost to the Kentucky line and is as useful to the Ohio geologist as the Vanport limestone is to the student in Pennsylvania. It always carries a marine fauna and in southern Ohio bears the same relation to the Ferriferous of Andrews that it does in northern Ohio to the Vanport or Ferriferous of Pennsylvania. In Barbour county of West Virginia, on the eastern outcrop, a limestone appears at a few feet

above the Brookville coal bed, and at one locality it is pure enough to be used as a flux. It has not been reported southward along this outcrop, but in Nicholas county one finds at the same horizon the very fossiliferous Black flint which in Nicholas, Fayette, and Kanawha counties is at 1 to 15 feet above the Brookville coal bed. This is confined to a small area and disappears quickly south from the Kanawha river. The Putnam Hill limestone is often cherty in Ohio. It is possible that the Kanawha flint may be equivalent to the Vanport, but its relation to the Brookville and the presence of a coal bed at some places just above it render the reference to the Putnam Hill horizon much more probable. The occurrence of this marine fauna in a very restricted area within the Kanawha district is as curious as that of the Campbells Creek fauna in the Pottsville within a somewhat smaller area in the same district.

The Brookville coal bed........ H. D. Rogers.	**In Pennsylvania, Cook of Broad Top, Brookville of authors, Clermont of McKean and Elk, Clarion of Ligonier valley, A; in Ohio, Brookville, No. 4; in Kentucky, Coal 5; in West Virginia, Upper Freeport, Lower Kittanning, Clarion, Arden, Roaring creek, Stockton.**

This is by far the most persistent coal bed in the formation. It is rarely of economic importance in Pennsylvania, for though often very thick it is usually a mass of alternating coal and shale, its coal high in ash and sulphur. In West Virginia along the eastern outcrop it becomes very important south from the Baltimore and Ohio railroad and is the only coal bed of the Allegheny on which mining operations are carried on over any considerable area. It is almost as important in that state as the Pittsburg is in southwest Pennsylvania. In Pennsylvania and even in West Virginia it is very apt to break up into many layers of coal and slate or into benches somewhat widely separated. The relations of this bed have been much in doubt, and in the tentative correlation used by the writer in describing the Pottsville the bed was regarded as equivalent to the Lower Kittanning; but since that part of this work was published additional records of borings have been secured which make the matter wholly clear in the critical locality within northern West Virginia, as will be seen on a later page. The Brookville seems to be the only horizon at which coal was formed over any considerable area in the interior of the basin, its coal having been found in Tyler, Wood, Jackson, and Cabell counties of West Virginia as well as in Monroe and Washington counties of Ohio, where no trace of any higher Allegheny bed appears in the records of oil-well borings. At the same time it does not extend across the basin, being absent in several counties east from those named. It is

quite persistent in Kentucky, though almost always very thin in that part of the state where correlation is possible. The distribution of these coals seems to make clear, as suggested by the writer upward of thirty years ago, that the coal beds were formed as fringes around the basin, some extending farther toward the center than the others, but all ending at a comparatively short distance from the shores. Coal or carbonaceous shale is reported at various depths within the central part of the basin, but these deposits bear no definite relation to each other or to the recognized horizons of the section, and in all probability they are mere accumulations of vegetable matter drifted upon mud lumps.

A matter of some interest which should not be overlooked is the occurrence of red shale in the upper part of the Allegheny within a little area in Ritchie, Wood, and Calhoun counties of West Virginia, and Washington of Ohio. No trace of red shale appears elsewhere within the Allegheny, so far as definite information is available, until one passes southwestward about 100 miles into Boyd county of Kentucky, where, near Cannonsburg, 18 feet of green and red shale appear between the Freeport coal beds. Green shales, however, seem to be characteristic of the Conemaugh in the southern areas and in the region beyond the Kanawha. Mr Campbell refers to his Braxton formation, including all deposits above his Charleston sandstone, as consisting chiefly of green and red shales and sandstones. In Boyd, Lawrence, and Carter counties of Kentucky green shales accompany the Freeport coal beds, while in southern Carter these green beds overlie the Lower Kittanning and in southern Lawrence they overlie the Middle Kittanning.

EAST FROM THE ALLEGHENIES

The insignificant area known as the Broad Top coal field, embracing parts of Bedford, Fulton, and Huntingdon counties of Pennsylvania, is of especial interest because of variations in the coal beds and in the intervals separating them. The following succession is a compilation of measurements made by Doctor White in Huntingdon and by Stevenson in Bedford and Fulton counties:

	Feet.	Inches.		Feet
1. Kelly coal bed	0		to	14
2. Shales and sandstone	65		to	120
3. Twin coal bed	1	6	to	6
4. Shale and sandstone	2		to	30
5. Barnett coal bed	1	9	to	5
6. Shale and sandstone	8		to	50
7. Cook coal bed	2	6	to	6
8. Clay and shale	2		to	20

to the Pottsville.

The Kelly coal bed, clearly equivalent to the Upper Freeport, disappears in the northern part of the field, but increases southward and becomes of great commercial importance in Bedford county, though even there it varies in thickness from 4 inches to 16 feet in one mine. It is usually double, and the parting has been found 1 inch to 10 feet on a single property. The upper division is ordinarily single, but the lower is often divided into several benches. The interval to the Twin coal bed is occupied at times wholly by shale, but on the western side of the field it contains a coarse sandstone which may be taken as representing both the Butler and the Freeport sandstone, as the Lower Freeport coal bed is not here. The interval in Huntingdon county varies from 90 to 110 feet, but in Bedford from 65 to 118, being greatest on the westerly side, where the sandstones are most prominent. The Twin coal bed is persistent throughout the field and derives its name from the fact that at times it and the Barnett below are almost in contact, so that they may be mined as one bed. In Bedford county the coal varies from worthless to good and in thickness from 1 to 6 feet, so that it is unimportant; but in Huntingdon its coal is good, and when near enough to the Barnett is mined. The interval to the Barnett varies from 6 inches to 30 feet, though rarely less than 2 feet. Within 200 rods, on Sixmile creek, in Bedford, the thickness was measured, 37, 19, and 7 feet. The thinning is toward the east, but not regularly so. In Huntingdon, Doctor White found it 8 to 30 feet on one property, but on another, in the eastern part of the field, the variation is from 6 inches to 7 feet. The Barnett coal bed always carries bony coal, 3 to 10 inches thick on top, and in the main coal usually shows two benches separated by a variable parting. At one mine Doctor White made this measurement:

	Feet.	Inches
1. Twin coal bed	2	0
2. Shale and rock	4	0
3. Barnett coal bed	17	9

	Feet.	Inches
Bony coal	0	9
Coal	2	6
Shale	3	0
Sandstone	11	0
Coal	0	6

This parting of 14 feet soon disappears, and in another part of the mine the bottom coal is in contact with the upper. The variability of this parting is a familiar phenomenon, as the mining operations on this bed are extensive within Huntingdon county. Doctor White correlates this bed with the Lower Kittanning of Blair county, to which it bears close resem-

blance in structure. The interval from the Barnett to the Cook coal bed is commonly about 50 feet; on the east side, in Huntingdon, it decreases to 35 feet, but midway in the field within Bedford a shaft shows it but 8 feet. A thick bed of fireclay underlies the Barnett and another overlies the Cook. In Bedford county the Cook coal bed varies from mere black shale to 7 feet of coal within a few rods; the quality of coal is inferior and the bed is not worked; but in Huntingdon county it has been worked, for the coal is thicker and better. It usually shows three or four benches separated by ordinarily thin partings, but one of these varies from 2 to 25 feet. On the east side of the field in this county the bed has its coals distributed through a vertical section of almost 48 feet.*

The Georges Creek, or Potomac, basin, originating in Bedford and Somerset counties of Pennsylvania, extends southward across Allegheny and Garrett counties of Maryland into Mineral and Tucker counties of West Virginia. Many measurements have been made by Messrs White, Martin, and O'Harra, from which five may be selected, which are as follows, arranged from north to south:

	I		II		III		IV		V
	Feet.	Inches.	Feet.	Inches.	Feet.	Inches.	Feet.	Inches.	Feet
Upper Freeport	5	0	4	2	5	4	5	2	8
Interval	20	0	60	0					
Lower Freeport	2	0	1	2	137	0	135	0	95
Interval	74	0	55	0					
Upper Kittanning	7	0	1	0	3	0	0	2	0
Interval	65	0	45	0	42	0	61	0	40
Middle and Lower Kittanning	5	6	6	5	6	4	8	5	11
Interval			85	0	80	0	121	0	65
Clarion	129	0	2	6	2	4	1	6	3
Interval			45	0	35	0	18	0	40

to the Pottsville.

I. Piedmont, West Virginia (I. C. White).
II. Above Harrison, Mineral county (I. C. White).
III. Harrison, Garrett county, Maryland (G. C. Martin).
IV. Henry, Garrett county, Maryland (G. C. Martin).
V. Thomas, Tucker county, West Virginia (I. C. White).

A full series of records published in 1906 shows that the Allegheny in this area varies from 260 to 350 feet, the thickness being greatest in the southern and eastern portions. The Upper Freeport coal bed, known locally as the Thomas, is persistent throughout, but increases in thickness

* J. J. Stevenson: Bedford and Fulton counties (T 2), pp. 62, 64.
I. C. White: Huntingdon county (T 3), pp. 52, 54, 55, 58, 59, 61, 66, 68.

and importance southward. At the north it is variable, usually in several benches or broken by numerous partings and often containing much bony coal. Southward, in the Potomac region, it is mined extensively, yielding at times 4 or 5 feet of good coal. The Lower Freeport is unimportant, yielding less than 2 feet of coal at the north and apparently disappearing southwardly, as at Henry there is only bone coal and at Thomas a mere trace. Between the Freeport coal beds, one finds occasionally a representative of the Upper Freeport limestone resting on the Butler sandstone, which is very massive and at times conglomerate. A limestone is reported in a borehole at Henry 16 feet thick and at a little way below the Lower Freeport, but no trace of it was observed elsewhere.

The Upper Kittanning is of very uncertain distribution, but at some localities in the Potomac region it has 3 to 4 feet of good coal. It is absent or insignificant in a great part of the area. The Middle and Lower Kittanning coal beds are separated in extensive areas by a mere parting, so that they are mined as one bed; but at Stoyer, in southern Garrett, this parting is 8 feet and elsewhere it increases to as much as 30 feet. The united bed is the Davis coal of the Potomac area and the Six-foot of the Georges Creek area. This bed has suffered much from "squeezes," the coal having been removed for considerable spaces both above and below the middle shale; but on each side of the disturbance the coal reappears and offers a large area free from the irregularity. It has suffered in this respect far more than any of the succeeding beds. At times the shale and bone partings so thicken as to render the bed unimportant commercially. The interval from Upper Freeport to Lower Kittanning varies from 170 to 210 feet. The Freeport sandstone is generally present, but varies greatly in thickness and structure. An irregular coal bed, known as the "Split-six," 30 to 46 feet below the Lower Kittanning, is present in the Georges Creek area. The available information does not justify an attempt to correlate it with any bed known farther west. A limestone appears occasionally below the Lower Kittanning in southern Garrett of Maryland and in Tucker of West Virginia, underlying iron ore in the latter. Doctor White and Doctor Martin see in this a representative of the Vanport (Ferriferous) limestone. It is nonfossiliferous here, but in the next basin westward a fossiliferous limestone has been found which is supposed to be very near this horizon.

A massive sandstone, in many respects closely resembling the Homewood of this region and at times 70 feet thick, is between the Lower Kittanning and the next coal bed below. This has been correlated with the Clarion sandstone by the Maryland geologists. Two coal beds are below the sandstone, the upper or Parker and the lower or Bluebaugh, separated

by an interval of 12 to 30 feet; the lower bed is the less persistent and is very close to the Homewood sandstone. If the overlying sandstone be the Clarion, it becomes necessary to regard these beds as representing the Brookville, which in much of the bituminous area is a complex bed, while farther southwest it occasionally divides in this manner; but the distance of this region from any other where the relations are distinct makes positive correlation impossible.*

FIRST BITUMINOUS COAL BASIN OF PENNSYLVANIA

This, extending from the Alleghany mountains westward to Laurel Hill, is traceable readily from Bradford county at the northeast across Lycoming, Clinton, Center, Clearfield, Cambria, and Somerset counties of Pennsylvania into Garrett of Maryland and Preston of West Virginia. It is divided in Pennsylvania by two anticlines, that at the west originating at the northern extremity and the other in southeast Cambria, so that the basin, double at the north, becomes triple in Somerset. The axes increase southwardly in Pennsylvania, Laurel becoming a bold mountain, the westerly fold growing into the great Viaduct axis and the Cambria fold developing into Negro mountain. The interior folds approach each other toward the Maryland line, so that the synclinal is too shallow to hold the Coal Measures in Maryland. The easterly, or Salisbury, subbasin of Somerset becomes shallow in Maryland and the Allegheny beds shoot out within 15 miles; but the western, or Johnstown, subbasin continues across Garrett into Preston of West Virginia, where, owing to the lessening strength of the Laurel anticlinal, the Allegheny beds become continuous with those of the Second Pennsylvania basin.

The somewhat widely separated patches of coal-bearing rocks within Bradford and Lycoming counties are confined to the western side of the basin. The Barclay area of Bradford county shows four coal beds in a vertical section of about 150 feet, which have been described by Mr Platt. How much of the section belongs to the Allegheny can not be determined.†

The Lycoming areas known as McIntyre and Pine creek are larger, and Mr Platt has measured the section there in detail as follows:

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* I. C. White: U. S. Geol. Survey Bull. no. 65, pp. 126-127; Geol. W. Va., vol. ii, p. 354.

C. C. O'Harra: Maryland Survey, Allegany county, p. 117.

G. C. Martin: The same, Garrett county, pp. 112, 115.

W. B. Clark et al.: The same, vol. v, pp. 298-299, 300, 333, 335-341. Advantage has been taken of delay in publication to insert here, as well as in the proper place under Conemaugh, additional material contained in volume v of the Maryland Survey, which has appeared since this manuscript was offered to the Society.

† F. Platt: Bradford and Tioga (G), pp. 125-127.

	Feet.	Inches
1. Sandstone and conglomerate	27	0
2. Black shale	1	3
3. Sandstone	21	0
4. Blue shale with plants	2	0
5. Coal and shale E	5	7
6. Fireclay	3	0
7. Sandstone and conglomerate	76	0
8. Coal bed, D	8	0

	Feet.	Inches
Coal	0	9
Clay and shale	5	0
Coal and shale	2	3

	Feet.	Inches
9. Fireclay	1	0
10. Sandstone and conglomerate	47	0
11. Coal and shale, C	7	4
12. Sandstone	19	0
13. Black shale, plants	2	0
14. Coal and shale, B	7	1
15. Clay, sandstone and shale	13	0
16. Coal and slate, A	9	10
17. Sandstone		

The same beds are present on Pine creek where the intervals are variable, that from A to B being 15 to 40 and that between D and E being 75 to 88 feet. The sandstone above E was taken by Mr Rogers, and afterward by Mr Platt, to be the Mahoning, thus identifying the bed E with the Upper Freeport. Bed B is the only one economically important. Mr David White's studies of the plant remains have made more than probable that the correlation made by the older geologists is incorrect, for he finds that the evidence would place bed B at the Mercer horizon of the Pottsville, so that bed E is probably in the Kittanning group.*

Two areas, no longer important, are in Clinton county, each showing the beds lettered A, B, D by Mr Platt. No information is given respecting the interval rocks. The Snowshoe field of northern Center county was studied by Mr Platt, whose section, revised by Mr d'Invilliers, is as follows:

	Feet.	Inches
1. Upper Freeport coal bed, E	5	0
2. Fireclay, concealed, sandstone	53	9
3. Lower Freeport coal bed, D	2	0
4. Ore and coal	2	0
5. Limestone [L. Freeport]	2	6

* F. Platt: Lycoming and Sullivan (G 2), pp. 93, 99, 125.
David White: Northern Appalachian coal field; 22d Ann. Rept. U. S. Geol. Survey, p. 136.

	Feet.	Inches.
6. Fireclay and black shale	39	4
7. Upper Kittanning coal bed, C′	7	8
8. Fireclay and shale	19	6
9. Sandstone	13	0
10. Middle Kittanning coal bed, C	4	0
11. Black shale, gray sandstone	28	6
12. Lower Kittanning coal bed, B	5	0
13. Concealed	45	0
14. Ore and sandy shale	18	0
15. Brookville coal bed, A	3	0

resting on fireclay, not measured, to the Pottsville. The Clarion was not seen in this shaft, but Mr d'Invilliers saw it at other localities 15 to 25 feet above the Brookville. The Gorman coal bed of the southern counties appears occasionally. The Upper Freeport consists of Bony coal 4 to 8 inches and 5 feet of good coal, with midway a slate 2 to 3 inches thick; but the Upper Kittanning, roofed by 2 feet of slaty cannel, is the more important bed, being available in a larger area. A long narrow strip of Allegheny occupies the easterly division of the basin in the southeast part of the county, where the Lower Freeport, worthless in Snowshoe, is worked and has this structure:

	Feet.	Inches
Bone coal	0	2 to 4
Coal	0	6 to 12
Cannel	0	2 to 3
Coal	4 to 5	0

and sometimes a thin streak of cannel in the main coal. No limestone was seen in any portion of this area.*

In Clearfield county one has Doctor Chance's partial section at Morrisdale, about 12 miles southwest from Snowshoe and on the westerly side of the basin. The Lower Freeport and Johnstown Cement limestones are here. The coal bed identified with the Upper Freeport is insignificant, but that taken to be the Lower Freeport is important and has the exact structure of the Upper Freeport at Snowshoe, thus:

	Feet.	Inches
Bone	0	2 to 8
Coal	3 to 2	6
Slate	0	1 to 2
Coal	1	3 to 2

* F. Platt: Clearfield and Jefferson (H), pp. 24, 41, 69.
E. V. d'Invilliers: Center (T 4), pp. 57, 64, 66-68, 70, 74, 81, 91, 106-107, 109, 113, 115.

A structure which bears no resemblance to that of the Lower Freeport is southwest Center. Doctor White's section at Houtzdale, 7 or 8 miles southwest from Morrisdale, is:

	Feet.	Inches
1. Mahoning sandstone, about	100	0
2. Upper Freeport coal bed	5	4
3. Interval	42	0
4. Lower Freeport coal bed and thick partings	13	0
5. Freeport sandstone and shale	36	0
6. Dark shale	14	0
7. Upper Kittanning coal bed	3	0
8. Fireclay and dark shale	33	0
9. Middle Kittanning coal bed	1	0
10. Slate, sandstone, shale	19	0
11. Lower Kittanning coal bed	4	0
12. Fireclay and shale	10	0
13. Hard sandstone [Kittanning]	32	0
14. Shales	21	0
15. Clarion coal bed [Brookville]	3	6
16. Hard fireclay		

The Upper Freeport has the same structure as in Snowshoe. No observer notes the occurrence of limestone until 8 miles west-southwest from Houtzdale, where Mr Platt found a 6-foot bed at 14 feet below a thin coal which he is inclined to take as Lower Freeport; but it may be the Upper Freeport limestone, as that is evidently present in the southern part of the county.*

The section is followed readily into Cambria, and at Bennington, on the Blair County border, Mr Fulton's long section shows all the coal beds present except the Gorman, with in addition a thin bed just above the Upper Freeport limestone. That is the only limestone in the section and is broken into many layers, which with the intervening shales occupy most of the interval to the Lower Freeport coal bed. Of the important sandstones, only the Freeport is noteworthy, the others being represented mostly or altogether by shale. At a few miles southwestwardly, in this easterly, or Wilmore, subbasin, many sections have been obtained, several of which have been grouped by Mr d'Invilliers. Condensed, these are:

* F. Platt: (H), pp. 34, 85, 105.
H. M. Chance: (H 7), pp. 38, 41-42, 53, 55, 61, 64.
I. C. White: Bulletin no. 65, u. 124.

	I		II		III		IV		V	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Upper Freeport	5	4	4	0	4	1	4	2	5	0
Interval	44	2	60	0	69	0	53	6	50	0
Lower Freeport	5	0	3	1	2	0	3	2	3	7
Interval	43	10	27	6	38	0	45	4	45	0
Upper Kittanning	2	10	2	6	4	0	5	4	2	7
Interval	54	9	80	0	68	0				
Middle Kittanning	3	8	3	0	1	8	94	4	97	11
Interval	38	0	23	0	22	0				
Lower Kittanning	3	6	4	0	4	0	3	3	4	6
Interval	35	8	22	6	20	0	33	10		
Clarion	1	8	2	0	5	0	0	2	68	11
Interval	30	0	28	3	29	8	..	..		
Brookville	5	0	4	9	1	8	..	..	3	6

I. Bennington (d'Invilliers).
II. Bens Creek (Prosser and Hardin).
III. Sonman shaft (Prosser and Hardin).
IV. Sonman borehole (Prosser and Hardin).
V. Wilmore borehole (d'Invilliers).

The Gorman coal bed is in the second, at 46 feet below the Upper Kittanning, and in the last a thin coal at 35 feet above the Lower Kittanning represents the Middle Kittanning. The Upper Freeport limestone is in the first three, while in the third, which is very near the east side of the basin, one finds for the first time the Johnstown limestone. The Lower Freeport limestone is shown on the southern border of the county. On the western side of Cambria, in the Johnstown subbasin, the Johnstown is the only limestone shown in Mr Fulton's section. It underlies the Upper Kittanning coal directly. The whole series of coal beds is present, but the only prominent sandstone is the Freeport—massive, micaceous, and 21 feet thick.*

Comparatively few details respecting the Allegheny are available in Somerset south from Cambria. The beds are reached for the most part only in gorges of Laurel hill or the Allegheny where the region is still largely forest. The Brookville and Lower Kittanning were recognized on the Allegheny, 50 to 60 feet apart, with another at 100 feet higher. The Upper Kittanning and both Freeports appear to be persistent in Negro mountain where the Lower Freeport and Johnstown Cement limestones are present. In the center of the county, near Somerset, the Freeport sandstone is massive and 30 feet thick; but there only the Johnstown

* F. Platt: Blair county (T), p. 95.
F. and W. G. Platt: Cambria (H 2), pp. 3, 4, 40, 41, 61-64, 100, 115.
J. Fulton in (H 2), pp. 97-98; Appendix to H 3, p. 367.
A. G. Prosser and O. B. Hardin: The same, 374, 377, 379.
E. V. d'Invilliers: Final Rept., 1895, plate 414, opposite p. 2220.

cement was seen. The Gorman coal bed is in some of the sections at 15 feet above the Middle Kittanning. A notable section was obtained by Mr W. G. Platt on Castlemans river, in the southern part of the county. It is as follows, the identifications being by the writer:

			Feet.	Inches
1. Upper Freeport coal bed			2	0
2. Shales and concealed			75	0
3. Lower Freeport coal bed			10	2
	Feet.	Inches		
Coal	2	10		
Bone and clay	4	0		
Coal	3	4		
4. Fireclay			2	0
5. Lower Freeport limestone			2	0
6. Fireclay and ore			3	9
7. Concealed			25	0
8. Upper Kittanning coal bed			Blossom	
9. Interval			3	0
10. Johnstown cement limestone			3	0
11. Concealed			5	0
12. Sandstone			18	0
13. Middle Kittanning coal bed			2	0
14. Fireclay and concealed			16	0
15. Sandstone			35	0
16. Lower Kittanning coal bed			17	6
	Feet.	Inches		
Coal	1	0		
Clay, sandstone	8	0		
Black shale	8	0		
Coal	0	6		
17. Concealed, shale, fireclay			33	0
18. Clarion sandstone			10	0
19. Brookville coal bed			14	4
	Feet.	Inches		
Coal	1	2		
Clay	3	0		
Shale	7	0		
Coal	1	6		
Shale	2	0		
Coal	1	6		
20. Concealed to Pottsville			10	0

Irregularity of deposit frequently characterizes all beds of the series, but it is especially characteristic of the Kittannings and lower coal beds. The Upper Freeport limestone is not in this section, but it is present elsewhere, being almost as persistent as the other limestones in the southern and western portions of the county. The Gorman and Clarion beds have not been recognized in Somerset.*

* F. and W. G. Platt: Somerset (H 3), pp. 122-123, 127, 129, 130, 194-195, 282-283.

Before following the section into Maryland it may be well to summarize the conditions in Pennsylvania. The thoroughly persistent coal beds are the Upper Freeport and Lower Kittanning, both of which attain great commercial importance in several parts of the basin. The others are of irregular occurrence and vary so in the quality of their coal that they are seldom of any importance. The intervals between the beds show great variation in almost contiguous sections, but it is worthy of note that the interval between the two important coal beds, Upper Freeport and Lower Kittanning, shows little variation in any given area. It exhibits great regularity as appears from this table:

	Feet
Snowshoe, Center county (F. Platt)	172 E.
Morrisdale, Clearfield county (Chance)	156 W.
Houtzdale, Clearfield county (I. C. White)	161 W.
Bennington, Blair county (Fulton)	179 E.
The same (d'Invilliers)	193 E.
Sonman, Cambria county	204 E.
Wilmore, Cambria county (d'Invilliers)	195 E.
Johnstown, Cambria county (Fulton)	181 W.
Hooversville, Somerset county (W. G. Platt)	195 W.
Castlemans, Somerset county (W. G. Platt)	200 W.

The letters refer to the east and west sides of the basin. From Clearfield southward there is evidently an increase in thickness of the measures.

No limestone is reported on the easterly side of this basin north from Cambria county, where one finds the Upper Freeport and at 3 or 4 miles farther south the Johnstown cement; but the Lower Freeport occurs on the westerly side as far north as Snowshoe, in Center, and the Johnstown cement is said to be in northern Clearfield. In central and in most of southern Clearfield all limestone is wanting practically, the limestone border evidently skirting the eastern edge. The distribution of the limestones geographically is capricious in the extreme, only the Johnstown being reasonably persistent; it is generally found wherever its horizon is exposed. The composition of the limestones is equally variable; each of them at times is pure enough to yield very fair lime, but they are frequently so siliceous or so argillaceous as to be worthless for any purpose, and such changes occur within short distances. None of them is markedly fossiliferous; several contain minute univalve shells, but distinctly marine forms were not seen in any. The Butler, Freeport, Kittanning, and Clarion sandstones are unimportant. The Freeport interval usually contains some sandstone, at times massive, even pebbly, but the other intervals are filled for the most part with shale except in Somerset and southern Cambria, where the Clarion is frequently a massive rock.

Passing over into Garrett county of Maryland, one has Mr Martin's measurements in the Salisbury subbasin at 7 or 8 miles from the Pennsylvania line. There the thickness of the Allegheny is given as 257 feet 6 inches. The Upper Freeport is in all 13 feet 5 inches thick, but contains a parting of almost 11 feet of black slate and a thin layer of bony coal. It is 136 feet above the bed designated Middle and Lower Kittanning, a mass of shale and coal 14 feet thick, with three thin benches of coal and two partings, each somewhat more than 5 feet thick. Midway between these beds is another consisting of two streaks of coal, 2 and 14 inches respectively, separated by 12 feet of shale. A sandstone 51 feet is below the Kittanning, and at 79 feet below that coal bed is another double bed, the benches 8 and 12 inches, with 14 feet of shale parting them. The relations are somewhat obscure, as the thickness of the Conemaugh is very much greater than at any other locality in this or any other basin, being given as 718 feet, while at a few miles west and north it is not far from 600 feet.

At a few miles west, near Oakland, another section is given, being the record of a boring; it is:

		Feet.	Feet
1. Mahoning sandstone			
2. Concealed, about		40	0
3. Lower Freeport coal bed		2	8
Consists of 8 layers of coal, bone and shale.			
4. Concealed, about		80	0
5. Sandstone, coarse to shaly		49	9
6. Shales		12	9
7. Middle and Lower Kittanning coal bed		3	9
	Feet. Inches		
Coal	1 4		
Bone	0 7		
Shale	0 6		
Coal	1 4		
8. Gray shale		13	4
9. Calcareous rock		1	2
10. Black shale		3	11
11. Split-six coal bed		1	7
	Feet. Inches		
Shale and bone	0 8		
Coal	0 11		
12. Shales, gray, green, red, black		73	6
13. Shales and sandstones		18	3
14. Fossiliferous limestone, ferriferous		1	2
15. Alternating shale and sandstone		17	0
16. Clarion coal bed		0	5
17. Fireclay, flint and plastic, shale		7	4

Here the interval from Lower Freeport to Middle Kittanning is about 143 feet; at the other measurement it is about 10 feet less from Upper Freeport to the Kittanning. The Split-six may be part of the Lower Kittanning. The fossiliferous limestone, Number 15, correlated with the Vanport of western Pennsylvania, is rich in marine forms, mostly brachiopods, at this locality. A limestone at varying distances below the Lower Kittanning has been observed in Garrett and Allegany counties of Maryland, but elsewhere in this region it contains only forms of doubtful affinity. Whether this be the same with the fossiliferous limestone of the boring can hardly be asserted positively. This Herrington-Manor limestone is at a very great distance below the Kittanning as compared with that of the Vanport farther west. The flint clay under the Clarion (Brookville) coal is a common feature farther west.

Doctor White gives a section in Preston county of West Virginia, within the Johnstown subbasin, which shows the Upper Freeport at about 56 feet above the Lower Freeport and about 141 feet above the Middle Kittanning, which is 90 feet above 1 foot of coal separated by 18 feet from a mass of coal and clay 8 feet thick. It is not impossible that the Lower Freeport of the Herrington-Manor section is the Upper, as the bed shows the same general structure throughout, but improves westwardly, being of much economic importance in this portion of Preston county.*

SECOND BITUMINOUS COAL BASIN OF PENNSYLVANIA

The Second bituminous basin of H. D. Rogers, lying west from Laurel Hill, is narrow and well defined, having in most of its extent the great anticline of Chestnut hill as its western boundary. The most northeasterly patches of Allegheny are in Tioga county, not far from the line of New York, whence the formation can be followed across Clinton, Center, Clearfield, Cambria, Indiana, Westmoreland, and Fayette counties of Pennsylvania into Preston county of West Virginia.

Mr Platt gives measurements at six localities in the Blossburg and other areas of Tioga county, showing six coal beds varying greatly in thickness, as do also the intervals between them. Only one of them is of economic importance, the Bloss, which is the fourth in descending order. Mr David White regards this as equivalent to the bed B of Lycoming county, which he refers to the Mercer horizon of the Pottsville. Only

* G. C. Martin: Maryland Geol. Survey, Garrett county, 1902, pp. 116-117, 119, 129. I. C. White: Bulletin no. 65, p. 76. W. Va. Geol., vol. ii, pp. 349, 409, 411.

the upper two beds can be placed in the Allegheny, and their relations to beds farther south can not be determined on stratigraphical grounds. The nearest measurement is that at Renovo, in Clinton county, 32 miles southwest, and the next, by Doctor Chance, is about 13 miles farther. These are not sufficiently complete to make comparison with the Tioga section or even with the detailed sections obtained in Center county and beyond.*

Mr d'Invilliers's section in Center county has a familiar look; this is about 15 miles northwest from Snowshoe, in the First basin. At a few miles southwest in Clearfield is Mr James's section at Karthaus, recorded by the First Pennsylvania Survey, and at Clearfield, nearly 15 miles farther, is a section by Doctor White. These in the order given are as follows:

	Feet.	Inches.	Feet.	Inches.	Feet.	Inches
Upper Freeport	3	6	6	0	4	4
Interval	50	0	47	0	50	0
Lower Freeport	Thin	0	0	10	2	6
Interval	42	0	32	6		
Upper Kittanning	2	8	3	0	70	0
Interval	34	0	38	6		
Middle Kittanning	3	0	3	2	1	6
Interval	45	0	33	0	35	0
Lower Kittanning	2	6	3	9	2	0
Interval	32	0	37	6	45	0
Clarion and shale	1	6	1	6	10	6
Interval	22	0	36	9	10	0
Brookville	2	6	1	0	2	0

The interval from Upper Freeport to Lower Kittanning varies from 158 feet 6 inches to 176 feet, but another measurement by Mr d'Invilliers in Center county gives only 163 feet 6 inches; so that the variation in this distance of about 30 miles is insignificant. Clearfield is 10 or 12 miles northwest from Houtzdale, in the First basin, where the interval is 161 feet. The "Big bed" of the Karthaus section is clearly the Upper Freeport, which is the important bed in this region, as it is in Snowshoe. The Lower Freeport is worthless, as in Snowshoe and in the First basin within Clearfield. The Gorman coal bed is reported in several sections, but as in the other basin is always unimportant. Doctor Chance's sections show that the Lower Freeport limestone is persistent as far north as Karthaus, beyond which it soon disappears. The Upper Freeport limestone is of

* F. Platt: (G), pp. 166, 174, 176, 186, 189.
C. A. Ashburner: (G 4), p. 74.
H. M. Chance: (G 4), p. 69.

uncertain occurrence and the Johnstown cement extends northward to but a little way beyond Clearfield.*

Mr d'Invilliers reports several sections in northwestern Cambria showing the varying intervals within an area of 8 or 9 square miles, thus:

	Feet.	Inches.		Feet.	Inches
Upper Freeport	3	6	to	4	0
Interval	33	0	to	50	0
Lower Freeport	3	0	to	4	6
Interval	35	0	to	46	0
Upper Kittanning	3	0	to	7	0
Interval	34	0	to	49	0
Middle Kittanning	2	0	to	2	0
Interval	35	0	to	45	0
Lower Kittanning	4	0	to	7	5
Interval	15	0	to	22	0
Clarion	1	8	to	1	10
Interval	30	0	to	30	0
Brookville	2	0	to	3	0

But while the intermediate intervals show such variation, that between the Upper Freeport and Lower Kittanning varies only from 163 to 168 feet, the increase being southwestwardly, which continues, for on Black lick the interval is 183 feet. The increase here is in the upper part of the section between the Freeport coal beds. Shales predominate in all of the sections, but the Freeport sandstone is present in two of them. The Upper Freeport and Johnstown cement limestones are present in several of the sections, especially on Black lick, where the Lower Kittanning is the important coal bed.†

In Indiana county the Second basin is known as the Ligonier valley, and this name is retained southward into West Virginia. Most of the area is covered by the Conemaugh, and the Allegheny is reached near the mountains. Near the Clearfield line the Upper Freeport is 8 feet 4 inches thick, carries on top 8 inches of bony coal, and is divided by a 4-inch parting, thus resembling the structure observed at many places in the First basin as well as farther north in this. A section on the west side not far from the Clearfield line is:

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* Geology of Pennsylvania: Vol. ii, p. 525.
E. V. d'Invilliers: (T 4), p. 124.
H. M. Chance: (H. 7), pp. 38, 41-42, 46, 53, 55, 61, 93, 96, 99, 103, 116, 129.
I. C. White: Bulletin no. 65, p. 123.

† E. V. d'Invilliers: Final Report, plates 415, 418, opposite pp. 2222, 2230.

	Feet.	Inches
1. Mahoning sandstone		
2. Upper Freeport coal bed	4	0
3. Fireclay, sandy shale	15	0
4. Black shale and thin coal	2	0
5. Upper Freeport limestone and clay	11	0
6. Fireclay	5	0
7. Interval	30	0
8. Lower Freeport coal bed	Thin	
9. Lower Freeport limestone, about	7	0
10. Interval	43	0
11. Upper Kittanning coal bed	Blossom	
12. Interval	50	0
13. Middle Kittanning coal bed	4	0
14. Mostly sandstone	40	0
15. Lower Kittanning coal bed	4	0
16. Black shale	20	0
17. Coal bed [Clarion]	0	6
18. Black shale	25	0
19. Clay shale	5	0

to the Pottsville. This is the most northerly exposure of the little coal on the Upper Freeport limestone, already seen at Bennington, in Blair county. The principal sandstones of the formation are wanting and the Brookville coal bed does not appear in the section. At 8 miles southeast, where an anticline brings up the Allegheny, the interval between the Freeport coals has increased to 76 feet, but that from Upper Freeport to Lower Kittanning is unchanged. At 6 miles southeast from this place the Freeports are 90 feet apart, but the interval between Upper Freeport and Lower Kittanning is barely 200 feet, a little less than in the measured section given above. The Clarion sandstone is massive, 25 feet thick, and rests on the Brookville coal bed, which is a mass of coal and shale 7 feet thick. On the Conemaugh river one finds the Upper and Lower Freeport and Johnstown cement limestones; the Freeport and Kittanning sandstones are distinct, though hardly cliff-making, while the Clarion is massive, 30 feet thick, and rests on the Brookville coal. The coal beds for the most part are not important. The Upper Freeport is often thick, but usually slaty; the Lower Freeport is variable in thickness and always poor, while the Lower Kittanning, though often thick and mined, never yields coal comparable with that obtained from this bed in Cambria county.*

Stevenson's work in Westmoreland and Fayette counties seems to disagree with that of observers in adjacent areas, because his nomenclature

* W. G. Platt: Indiana (H 4), pp. 65, 121, 125, 139, 145.

differs from that employed by Mr Platt. At the time his work was done the succession of the Allegheny coal beds had not been determined and the nomenclature had not been fixed. The terms employed by him should be corrected as follows to agree with Professor Lesley's classification published in the Armstrong report in 1880:

Upper Kittanning limestone.	Johnstown cement.
Lower Kittanning.	Middle Kittanning.
Clarion coal bed.	Lower Kittanning.

Stevenson gives a section on the east side of the basin showing 160 feet of conglomerate, beginning at 120 feet below the Upper Freeport, and identifies the coal resting upon it with the Brookville. But this was an error, for there one has merely an enormous expansion of the sandstones at the bottom of the Allegheny, making them continuous with the Pottsville, as in many extensive areas within western Pennsylvania and West Virginia. The interval between the Freeport coals is as variable as in Indiana; at 10 miles south from the Conemaugh, on the east side of the basin, those coals are 92 feet apart, with all members of the section present down to the Johnstown cement; but within a few miles this interval decreases to 39 feet in a section showing all three of the limestones. The general succession in Westmoreland and Fayette is shown by a section in each county, thus:

		Feet.	Inches.		Feet.	Inches
1. Upper Freeport coal bed		4	0		3	0
2. Interval		62	0		44	0
3. Lower Freeport coal bed		0	6		0	6
4. Interval		18	0		30	0
5. Upper Kittanning coal bed and shale		6	7	4 to	7	0
6. Interval		47	7			
7. Middle Kittanning coal bed	3 to	4	0		118	0
8. Interval		51	6			
9. Lower Kittanning coal bed		5	0		Blossom	
10. Interval		75	0		60	0
11. Brookville coal bed		2	0	2 to	3	0
12. Shale and clay		25	0		10	0

to the Pottsville. The Clarion coal bed evidently disappears in southern Indiana, as no trace of it was seen in any Westmoreland section, though in some cases the exposure below the Lower Kittanning (Clarion of Stevenson) is complete. The Brookville is persistent to the Maryland-West Virginia border, often attaining a considerable thickness and yielding good coal, though ordinarily so badly broken by clay beds as to be unavailable. The Lower Kittanning is persistent, but is seldom workable,

for when thick it contains much refuse. Stevenson reports it as 5 feet 11 inches at one locality in Fayette, but Campbell has proved the identification erroneous and the bed is probably higher in the formation. The Middle and Upper Kittanning rarely attain even local importance; usually thin, they sometimes thicken up to a worthless mass of coal and shale. The Lower Freeport is always insignificant. The Upper Freeport becomes very thick on the west side, but is broken by partings. At one locality near the West Virginia line it is 9 feet 7 inches thick, with 16 layers of coal, shale, and clay. On the easterly side it is commonly double, 2 to 6 feet thick, but the coal is tender, sulphurous, and high in ash.

The Upper Freeport limestone appears in most of the sections, but the Lower Freeport appears rarely south from Westmoreland, and the Johnstown seems to be absent from Fayette. The Freeport and Kittanning sandstones are distinct, rarely other than massive in these counties.*

The intervals between the several coal beds show as great variation as in the First basin, but that between the Upper Freeport and the Lower Kittanning shows narrow variations within considerable areas; these may be summarized thus:

	Feet.		Feet
Center (d'Invilliers)	163	to	176
Clearfield (James)	168		
Clearfield (I. C. White)	169		
Northwest Cambria (d'Invilliers)	163	to	168
Western Cambria	183		
Indiana (W. G. Platt)	207		
Northern Westmoreland (Stevenson)	251		
Central Westmoreland (Stevenson)	189		
Southern Fayette (Stevenson)	197		

North from Fayette county the presence of the three limestones in almost all of the sections renders the identifications certain. These limestones are non-fossiliferous and show as notable variation in composition and in appearance as they do in the First basin.

Passing over into Preston county of West Virginia, one finds at 12 or 13 miles from the Pennsylvania line the following measurements of cores obtained by diamond drill:

	Feet.	Inches
1. Upper Freeport coal bed and partings	10	2
2. Fireclay, limestone, sandstone	21	1
3. Green shale and sandstone	14	2
4. Gray sandstone, Upper Freeport [Butler]	29	8
5. Lower Freeport coal bed	1	1

* J. J. Stevenson: Ligonier valley (K 3), pp. 89, 135, 158, 172.
M. R. Campbell: U. S. Geol. Survey folio, Masontown-Uniontown, 1903.

	Feet.	Inches.
6. Fireclay, green shale, sandstone	7	6
7. Hard pebbly sandstone [Freeport]	76	4
8. Black shale, Middle Kittanning coal bed	8	5
9. Slate, shale, fireclay	61	8
10. Gray sandstone	6	1
11. Slate and coal	1	0
12. Shale	7	6
13. Clarion coal bed [Brookville]	9	1
14. Fireclay	12	10

to the Pottsville sandstone. The Upper Freeport is 86 feet below the Brush Creek limestone, which is embedded in black fossiliferous shale immediately overlying the Brush Creek coal bed. The interval from Upper Freeport to the Middle Kittanning is 146 feet, and to the top of the fireclay which underlies the place of the Lower Kittanning 199 feet, almost the same as in southern Fayette. The Brookville coal bed is worthless, in two nearly equal benches of slaty coal, separated by 6 feet 5 inches of fireclay. The Lower Freeport is a double bed and the Upper Freeport is in 13 layers of coal, bone, and slate.

At a few miles farther south this Second basin, owing to the decreasing strength of Chestnut hill, becomes continuous with the western basins, and it will be described in connection with the West Virginia area.*

WESTERN BASINS OF PENNSYLVANIA

The region west from Chestnut Hill anticline to the Ohio line may be considered as one, there being no very strongly marked divisions.

A small area of Coal Measures remains in Tioga and Potter counties near the line of New York, in which the upper part of the section may belong to the Allegheny, but, as Mr David White has shown, the greater part belongs to the Pottsville, according to the testimony of the plant remains. The distance from other areas is too great to admit of correlation on any other basis.

Some isolated patches remain in McKean county, west from Potter, the most northerly being about 10 miles north from the line of Elk county, where the section reaches upward to the Middle Kittanning coal bed. The persistent coals are those named Dagus and Clermont, which Mr Ashburner identifies with the Lower Kittanning and Clarion. Between them is the Vanport (Ferriferous) limestone at 8 to 30 feet below the Dagus coal, wanting, however, at the most northerly exposure as well as in the southeastern part of the county, and, where present, somewhat impure, though at times 8 feet thick. The interval between Dagus and

* I. C. White: Geology of West Virginia, vol. ii, pp. 311, 344.

Clermont varies from 43 at the north to 78 feet in the southeast, an intermediate measurement being 51 feet. A thin coal bed, without value, seen occasionally between the Dagus and Clermont, is regarded by Mr Ashburner as probably the Scrubgrass coal bed of I. C. White, belonging under the Vanport limestone.*

The shallow synclines of northwest Cameron, west from Clinton and Potter, south from McKean, carry patches of Allegheny showing the three coal beds of McKean, which are separated by intervals of 29 feet 6 inches and 52 feet, the interval between Dagus and Clermont being 84 feet 6 inches, 6 feet greater than in the adjacent part of McKean. The Vanport limestone is absent. This section would place the Clermont coal bed at the Brookville horizon.†

The complete Allegheny section is reached in southern Elk county, west from Cameron and south from McKean. The Middle Kittanning is the highest bed in Jones, the northern township, where the intervals are greater than in McKean, and 40 feet of shale separate the Lower Kittanning and the Vanport limestone. The latter, 9 feet thick and double near the northern line, becomes a calcareous chert in the southern part of this township as well as in Ridgway, but in the southeast part of the county it is again a limestone. A thin coal bed, Ferriferous of Ashburner, but clearly the Scrubgrass, directly underlies the Vanport in the northern townships, but is wanting at the southeast in Benzinger, where the Clarion coal bed, 5 inches thick, is at 13 feet below the limestone and 16 feet above the Clermont (Brookville) coal bed.

At the Dagus shaft, near the Clearfield border, Mr Ashburner recognizes the Freeport coal beds, 60 feet apart, with the Johnstown cement limestone at somewhat more than 60 feet below the Lower bed. The Upper Kittanning is not exposed above the shaft, but in the shaft the Middle Kittanning is shown at 163 feet and the Lower Kittanning at 212 feet below the Upper Freeport. The Vanport limestone is 40 feet below the Lower Kittanning, and another coal bed is reached at 25 feet lower, which is correlated with the Clarion, but is more likely to be at the Brookville horizon. The interval between the Lower Freeport coal bed and its underlying limestone varies usually 2 to 5 feet, but in Horton township, near the southern border of the county, it varies from 52 to 69 feet and contains two coal beds, 2 and 3 feet thick; the accuracy of Mr Ashburner's identifications can not be doubted, for all four limestones are present in his sections, the Vanport being richly fossiliferous and 35 feet above the Clarion (Brookville) coal bed. The Upper Freeport is divided by a

* C. A. Ashburner: McKean county (R), pp. 45, 99, 127, 133, 139, 171-172, 189.
† A. W. Sheaffer: Cameron (R R), pp. 46-50.

parting which is from a mere film to 20 feet thick. The most northerly point at which the Vanport is fossiliferous is in Fox township.*

A few patches remain in Forest county near the Elk border, showing 50 feet of shales and sandstone overlying the Clarion (Brookville), which is 2 feet thick and rests on the Homewood sandstone. The Vanport limestone was not seen.†

Venango county, southwest from Forest and west from Clarion, has scattered patches in the south and southeast portion, in one of which Doctor Chance measured:

			Feet
1. Ferriferous limestone [Vanport]			8
2. Blue slate			2
3. Coal bed [Scrubgrass]	1	to	2
4. Concealed	8	to	10
5. Sandstone [Clarion]			56
6. Slate			6
7. Coal bed [Brookville]			2

The Vanport limestone is of uncertain occurrence.‡

In the extreme northern part of Jefferson county, south from Elk and Forest, west from Clearfield, the Allegheny has been removed, but in most of the county it is the surface formation, and the Upper Freeport is available in an extensive area within the southern third as well as in the northeast near Brockwayville. A section at the latter locality shows:

	Feet
Upper Freeport.	
Interval	43
Lower Freeport.	
Interval	45
Upper Kittanning.	
Interval	54
Middle Kittanning.	
Interval	45
Lower Kittanning.	
Interval	75
Brookville.	

These intervals vary little from those of Elk county, except that the Freeports are 43 instead of 54 to 70 feet apart, and the interval from Upper Freeport to Lower Kittanning is only 187 feet. The Butler and Freeport sandstones are conspicuous, but the Kittanning interval is occupied by

* C. A. Ashburner: Elk (R R), pp. 69, 73, 106, 112-113, 150, 153, 186, 214, 217-218, 227, 241, 245, 254.

† C. A. Ashburner: Forest (R R), p. 307.

‡ H. M. Chance: Oil Regions (I 3), pp. 437-438.

shale. All of the limestones are here. In the central and northwestern parts of the county the whole interval from the Vanport down is filled with sandstone, mostly massive, but the normal condition exists in the north central part, where one finds the Middle and Lower Kittanning, 55 feet apart, and the Scrubgrass, or Upper Clarion, directly underlying the Vanport limestone, is 35 feet above the Brookville, which rests on the Homewood sandstone. The coal beds of the Kittanning and Clarion groups, though persistent and at times of workable thickness, rarely yield good coal. The Lower Freeport, somewhat variable in thickness, is important, as it yields good coal, while the Upper Freeport, equally persistent, is of little value. The Vanport limestone changes in the northwest part of the county into cherty limestone, and then into calcareous sandstone. Eastwardly it thins out and seems not to extend beyond the middle of the county. Of the other limestones the Johnstown cement is present in sections showing its place, the Lower Freeport is very irregular, and the Upper Freeport, persistent in the east and south, is apparently absent in the middle and northwest portions. The great sandstones are represented usually by shale.*

Indiana county is south from Jefferson and its larger part lies west from Chestnut hill. A narrow area exposing the Allegheny stretches along the west slope of that ridge from Jefferson county to the Conemaugh river, whence it extends southwardly across Westmoreland and Fayette into West Virginia.

Near the Jefferson border the Upper Freeport shows the structure so often observed in the Second basin and is 5 feet 2 inches thick, but yields worthless coal. The interval to the Lower Freeport is 75 feet and both limestones are present. The Upper Kittanning at 50 feet lower shows at one locality the feature observed already in that bed as well as in the Lower Freeport and to a somewhat less extent in the Middle Kittanning, thus:

	Feet.	Inches.	Feet.	Inches.	Feet.	Inches
Bony coal or cannel....	1	3	8	3	1	2
Coal, good but friable...	2	7	2	7	2	7

The upper division has 21 to 24 per cent of ash and the lower 1.6, while the sulphur is practically the same in both, .621 to .654. This "pot" of thick cannel embraces only a few acres. The Johnstown cement limestone is here with the Gorman coal bed 3 feet thick and 2 feet below the limestone. The Lower Freeport farther south is very irregular; the Vanport was not seen by Mr Platt, but Mr Richardson has recognized it

* W. G. Platt: Jefferson (H 6), pp. xxx-xxxii, 100, 111, 187, 190, 199.

in a well on Ramsay run, 4 feet 5 inches thick and 238 feet below the Upper Freeport coal bed. He found traces of it on the slope of Chestnut hill at 80 feet above the Pottsville and 20 feet below the Lower Kittanning coal. On Yellow creek the intervals are much reduced, the Upper Freeport, Lower Freeport, and Upper Kittanning being but 55 and 25 feet apart, the associated limestones being present. A thin double coal bed, often seen in the Second basin, is here at 11 feet below the Upper Freeport and 3 feet above the limestone. The intervals increase southwardly, for on Black Lick creek the Upper Kittanning is 100 and the Lower Kittanning 189 feet below the Upper Freeport. The coals are all poor. The Freeport and Clarion sandstones are conspicuous, fine grained, and current bedded. The Johnstown cement is apparently the only limestone present. From this stream to the Conemaugh the section is clear. The little coal bed below the Upper Freeport persists. The Vanport limestone is present midway in the county where an anticline brings it up.*

Clarion county is south from Forest and west from Jefferson. In the northern portion the section seldom extends above the Middle Kittanning, and the whole section is found only in some widely separated areas within the southern part of the county.

North from the Clarion river one finds all of the coals below and including the Middle Kittanning. The interval from Lower Kittanning to the Vanport limestone varies from 8 to 20 feet without seriously affecting the interval from the limestone to the Middle Kittanning. Doctor Chance shows by a grouped series of sections that the Scrubgrass and Clarion are but splits of one bed. The varying intervals between the beds in southern Clarion are shown by these measurements, which are arranged from east to west:

I. Near Fairmont, Red Bank township.
II. In same township.
III. New Bethlehem, Porter township.
IV. Wildcat, Toby township.
V. Hillville, Madison township.

	Ft.	In.	Ft.	Ft.	Ft.	In.	Ft.	In.
Upper Freeport	4	0	4	..	..	..	2	0
Interval			40	45				
Lower Freeport	108	0	6	7	..	..	108	0
Interval			95	68				
Upper Kittanning	1	1	2	2	1	6	1	5

* W. G. Platt: Indiana (H 4), pp. 187, 189, 191-192, 205, 209, 211, 220, 223, 226-227. G. B. Richardson: U. S. Geol. Survey folios, Indiana, 1904.

	Ft.	In.	Ft.	Ft.	Ft.	In.	Ft.	In.
Interval	40	0	45	47	50	0		
Middle Kittanning	1	3	2	2	3	8	66	6
Interval	48	0	30		37	0		
Lower Kittanning	2	6	4	64	3	0	3	6
Interval	35	0	33		25	0	40	0
Vanport limestone	5	0	4	4	7	0	10	0
Interval							22	0
Clarion	..	..	..	50	..	..	2	2
Interval							23	0
Brookville	..	..	..	..	..	..	Thin	

to the Pottsville. The interval from Upper Freeport to Lower Kittanning in the three sections showing both beds is 198, 220, and 176, and to the Vanport 235, 271, and 219 feet, the last in the southwest corner of the county. At one mile north from III the interval between Lower Freeport and Upper Kittanning is but 40 feet, and at two miles south, in Armstrong county, it is only 25 feet, showing a variability in this interval such as has been noted already in southern Elk. Of the limestones, the Upper Freeport is widely distributed, the Lower Freeport and Johnstown cement are irregular, while the Vanport seems to extend in prongs toward the northwest. The Butler, Freeport, and Kittanning sandstones are distinct in the southern townships, but elsewhere their places are filled for the most part by shales, while the Clarion is a well marked sandstone, 20 to 30 feet thick, in most of the county. The Upper Freeport coal bed is good, with little variation in thickness, but the other beds are of no importance except the Upper Kittanning, which, in a small area within Porter township, has a cannel roof of 8 feet.*

Armstrong county, south from Clarion, west from Indiana, and north from Westmoreland, has for its southern boundary the Kiskiminetas, the continuation of the Conemaugh river. In the easterly part of the county the section is followed easily from Clarion line to the Kiskiminetas, though the intervals between the coal beds show notable variations. The Scrubgrass, or Upper Clarion, coal bed does not appear in any of the sections, but the others are persistent, though the Upper Freeport and Lower Kittanning are the only ones of economic importance. The Upper Kittanning has a cannel roof 8 feet thick in a small area adjoining Clarion county, but the cannel is inferior. The Upper Freeport and Vanport limestones are persistent except in a small area central in the county where the lower bed seems to be wanting. The sandstones are insignificant and their places in almost all of the sections are filled with shale.

* H. M. Chance: Clarion (V V), pp. 70-71, 75, 77, 79, 80-81, 88, 90-91, 95, 97, 103, 107, 112, 121, 123, 125-126, 132, 136, 142-143, 147, 153, 158, 160, 175-176, 178, 181.

In the western part of the county, beyond the Allegheny river, one reaches the western limit of the Johnstown cement, which is absent at the north though present at the southwest in unimportant development. Of the other limestones, the Upper Freeport and Vanport are persistent, but the Lower Freeport is very irregular. The Freeport sandstone is conspicuous and at times, as in a portion of Jefferson county, sandstone fills practically the whole interval from the Vanport to the Homewood sandstone. The coal beds are unimportant, though the Upper Freeport is good at the north, and in many places the Upper Kittanning shows its tendency to accumulate cannel slate on top. Two measurements, one at the north, the other at the south, show the relations of beds on this western side:

	Feet.		Feet.	Inches	Feet.		Feet.	Inches
Upper Freeport			7	0			2	6
Interval			60	0			54	0
Lower Freeport	4	to	1	6			1	0
Interval			65	0			35	0
Upper Kittanning	12	to	0	10			1	0
Interval			45	0				
Middle Kittanning			4	0			117	0
Interval	35	to	40	0				
Lower Kittanning			3	6	3	to	4	0
Interval			33	6			25	0
Vanport limestone			15	0			Thin	
Interval			30	0			25	0
Clarion	2	to	3	0			2	6
Interval	22	to	32					
Brookville			Thin					

But the interval from the Upper Freeport to the Lower Kittanning is practically the same in both sections.*

Butler county, south from Venango, west from Armstrong, is east from Mercer, Lawrence, and Beaver.

The Vanport limestone is present throughout except in small patches at the northwest. The Lower Kittanning, hitherto the most persistent of the coal beds, is somewhat uncertain on the northern border and seems to be wanting in considerable areas within the central part of the county. The interval to the Vanport varies from 10 to 45 feet, the least thickness being on the Lawrence border at, say, 10 miles south from the Venango line; thence it increases eastwardly to 15, 20, 30, and 45 feet within 10 miles, and similar increase appears southwardly. The Middle Kittanning is persistent, and in the absence of the Lower Kittanning might be

* W. G. Platt: Armstrong (H 5), pp. 6, 9, 16, 67, 92, 100, 105, 109, 115, 122, 143, 147, 153, 165, 177, 191, 215, 222, 224, 267, 271, 288.

mistaken at times for that bed, as the interval to the Vanport varies from 45 to 90 feet, diminishing westwardly. This bed is 40 to 60 feet below the Upper Kittanning, which is 110 to 130 feet above the Vanport, and in some of the townships is largely a cannel. The interval between Upper Kittanning and Lower Freeport is as variable as in Elk, Clarion, and Armstrong, the extremes in a single township being 55 and 91 feet. Where the Freeport sandstone, occupying this interval, is divided by shale, a coal bed, the Currie, occasionally appears. The Lower Freeport is roofed by laminated shale and coal a few inches to 10 feet thick, and the Upper Freeport, 50 to 60 feet higher, is uncertain, apparently wanting at many localities.

The Scrubgrass, Clarion, and Brookville coal beds below the Vanport limestone may have been deposited in the greater part of northern Butler, but they are now wanting in the western portion, where for the most part the Clarion sandstone is continuous with the Pottsville. The Freeport limestones appear in only a few sections and the Johnstown cement is absent.*

The surface rocks in southern Butler for the most part are Conemaugh, but the Allegheny beds are reached on the east side in deep valleys tributary to Buffalo creek and on the north and west in the valley of Connoquenessing creek. Two measurements on the east or Armstrong side are important for correlation:

	Feet.	Inches.	Feet.	Feet.	Inches
Upper Freeport	..	..		3	2
Interval	..	..		65	0
Lower Freeport	Blossom		1 to	2	0
Interval	80	0			
Darlington [Upper Kittanning]	3	0		147	0
Interval	70	0			
Kittanning [Lower]	10	9		3	0
Interval	55	0		55	0
Ferriferous limestone [Vanport]	15	0		16	6
Interval	20	0		12	0
Clarion	2	0		3	0
Interval	10	0		30	0

to sandstone. The interval from Lower Freeport to the Upper Kittanning (Darlington) is very like that in much of northern Butler and northwest Armstrong, but nearly double that in southwest Armstrong, while the interval from Lower Freeport to Lower Kittanning is actually

* H. M. Chance: Northern Butler (V), pp. 17, 28, 95, 97, 103, 105, 121, 123, 125, 129, 130, 132, 134, 137.

the same as in the last. The interval between Upper Kittanning (Darlington) and Lower Kittanning in western Armstrong varies from 95 to 117, that between Lower Freeport and Lower Kittanning remaining the same, while in central Butler, Doctor Chance's section shows about 85 feet to the bottom of the Lower Kittanning, differing little from the interval in these measurements by Doctor White. The Lower Kittanning is from 3 to 11 feet thick and one of its benches yields good coal; the other beds are without value. The Butler and Kittanning sandstones are massive. In the southwest corner of the county the Freeport coal beds are 45 feet apart and the Darlington (Upper Kittanning) is 145 feet below the Upper Freeport. The Freeport sandstone is massive and the Upper Freeport limestone is present in most of the sections.

On the Connoquenessing the Freeport coals are of little value and are 55 to 80 feet apart. The interval from the Lower bed to the Darlington varies from 43 to 70 feet, the smaller interval being on the western border, where the Darlington is barely 125 feet below the Upper Freeport. At a few miles north from this exposure a coal bed, known as the Eichenaur and commonly supposed to be a local bed, is seen at 115 feet below the Upper Freeport. It is variable, cannel on top, coal below, but changing into bituminous shale. This is very like the Upper Kittanning (Darlington), which in the neighboring township of Forward is only 120 feet below the Upper Freeport. The Freeport and Butler sandstones are usually massive along the Connoquenessing valley. A boring in Forward township shows the whole interval from the Homewood sandstone up to what may be the Middle Kittanning coal bed filled with sandstone. The Freeport limestones appear in most of the sections, none of which goes down to the place of the Vanport. The coal beds are poor and of no economic importance, though the Lower Freeport and Upper Kittanning (Darlington) are mined for local use.*

The northern border of the Allegheny formation, owing to shallowing of the synclinals, falls southwardly toward the west, so that in Mercer county, west from Venango and Butler and extending to the Ohio line, one finds rocks higher than the Vanport (Ferriferous) limestone only in the southeast corner near the Butler line. Doctor White's sections show the Lower Kittanning at 45 feet above the Vanport limestone and at the same distance below a coal bed termed the Darlington locally. The Darlington of Mercer is not the same with the Darlington of southern Butler; that of Mercer is the Middle Kittanning; that of southern Butler is the Upper Kittanning. The Mercer County measurements are only

* I. C. White: Southern Butler (Q), pp. 90, 92, 94, 95, 110, 111, 112, 117, 119, 120, 130, 133, 135-139.

5 or 6 miles west from measurements in northern Butler where the Middle Kittanning is 70 to 80 feet above the Vanport limestone and 40 feet below the Freeport sandstone, and about 10 miles west from Murrinsville, in that county, where the Upper Kittanning is 120 feet above the Vanport. The Scrubgrass and Brookville coal beds are here, the latter at 27 to 55 feet below the Vanport, the interval decreasing westwardly. The limestone is not persistent, but where present is richly fossiliferous. At one place it is 12 feet thick.*

Areas of Allegheny become more extensive in Lawrence county, south from Mercer and west from Butler. The section lengthens and the Upper Freeport coal bed is reached at many localities. The Darlington coal bed of this county is the Middle Kittanning.

On the east side the Middle Kittanning is 70 to 80 feet above the Vanport (Ferriferous) limestone, the interval depending on that between the Lower Kittanning and the Vanport, which varies from 15 to 25 feet, and that between the coals from 40 to 58 feet, these variations being similar to those in the adjacent part of Butler county. The Upper Kittanning is missing and the Middle is at 140 feet below the Upper Freeport, in the southern part of the county. Westwardly, in the northern and middle parts of the county, the Middle Kittanning is quite regularly 70 to 80 feet above the Vanport, but along the southern border the interval varies from 100 to 65 feet, the latter at the west near the Ohio border. The Vanport limestone is not wholly persistent, being wanting in a considerable area, but it is found in most of the county, 15 to 25 feet thick, always double, gray above, blue below, and everywhere richly fossiliferous in both divisions. The Scrubgrass and Brookville coals appear in a number of the sections, but they as well as the higher coals are of little importance.

The interval from Upper Freeport to Lower Kittanning is 208 feet in eastern Butler, 190 to about 200 in eastern Lawrence, but decreases to 160 feet near the Ohio state line.†

Beaver county is south from Lawrence along the Ohio line. North from the Ohio river one occasionally finds the Brookville and Clarion coals 15 to 50 feet apart and very thin, at times distributed through a mass of carbonaceous shale. The Vanport limestone is very thick, 22 feet, in the northeast, but becomes thinner southward and westward until, on the river near the Ohio line, it is but one foot thick, and soon after crossing into Ohio it practically disappears. At Homewood station, midway

* I. C. White: Mercer (Q 2), pp. 22, 32, 77, 79, 88, 132.

† I. C. White: Lawrence (Q 2), pp. 76, 84, 86, 92, 94, 98-99, 111, 115, 121-122, 131-132, 134-139, 141, 144, 146-147, 152, 159, 161, 162-166, 169, 171, 179, 187, 196, 199.

in this portion of the county, it is replaced by sandstone which is continuous below with the Pottsville. The Lower Kittanning coal bed, at 50 to 80 feet above the Vanport, is persistent throughout the county and rests on a thick bed of clay which is of great economic importance. The Middle Kittanning (Darlington) coal bed is at 50 to 20 feet above the Lower Kittanning, the least interval being on the river one mile from the state line. Near the river this bed is unimportant, but northward it shows some changes which make it locally important. At one locality it shows:

	Feet.	Inches
Cannel slate	6	0
Cannel	12	0
Coal	3	6

The slate is rich in carbonaceous matter, one ton yielding on distillation one barrel of oil; but an enlargement of this kind is very local, thinning out in each direction until only the coal is left, and possibly within a short distance the whole deposit was cut away by the overlying sandstone. The interval to the Lower Freeport coal bed is occupied mostly by sandstone, the continuation downward of the Freeport. Occasionally this mass is interrupted by shale, and then a coal bed is shown at 15 to 20 feet above the Middle Kittanning, which may mark the Upper Kittanning, which otherwise is without representative in this region. The Lower Freeport coal bed is insignificant; the Upper Freeport is usually double or triple, with thin partings and a thickness of about 4 feet; but at one place it resembles the Middle Kittanning, having a roof of coal and cannel 5 feet thick. The Freeport and Kittanning sandstones are usually massive.*

Southward from the line of Beaver, Butler, Armstrong, and Indiana counties the Allegheny formation is nowhere completely above drainage except along the westerly slope of Chestnut hill, in Westmoreland and Fayette and perhaps under the Fayette anticline on the Youghiogheny river in Fayette;† elsewhere to the West Virginia line it is for the most part buried under the Conemaugh, and dependence must be placed upon the records of oil borings.

In Westmoreland and Fayette the Allegheny coals have been mined to very slight extent, owing to proximity of the great Pittsburg coal bed, and exposures in the mountain gorges are usually too indefinite to make accurate measurements possible. The information contained in Stevenson's reports is fragmentary and of little value. The Upper Freeport coal

* I. C. White: Beaver (Q), pp. 40, 42, 47, 48, 50, 110, 194, 209, 225, 233-234, 249, 253, 260, 265; Ohio line (Q 2), 254, 258, 260, 263.

† M. R. Campbell: U. S. Geol. Survey folio, Masontown-Uniontown, 1903.

bed persists along the whole line and is opened at many places for use of the farmers. Usually it is in numerous benches, separated by clay partings, so that although it is very thick at times, 11 to 16 feet, it is apparently unimportant. The Lower Freeport was seen on the Conemaugh at 47 feet below the Upper, and also at several places south from the Youghiogheny river, but it is worthless. The Brookville or possibly Clarion was seen at many places, at times in several benches of fair coal separated by thick clay partings which vary at the expense of the coal. Two other beds were seen which unquestionably belong to the Kittanning group, the lower one being above a sandstone which is probably the Kittanning. This is a well marked rock in the southern part of this strip, and it is called Piedmont in Stevenson's reports, in accordance with Professor Lesley's correlation in the Coke Report. The Freeport limestones seem to be present near the West Virginia line.*

Returning to the north and following the formation under cover, one has oil records, many of which are referred to the Ames limestone as the datum. In Allegheny and Westmoreland counties that limestone is from 280 to 300 feet below the Pittsburg coal bed. In Allegheny north from the Ohio river the occurrence of the coal beds soon becomes very irregular, as might be expected from conditions in adjacent parts of Butler and Beaver. Seven records are available in western Allegheny near the Beaver line. Two of these show no coal, one has three beds, 69 and 34 feet apart, while in one or the other of the remaining wells one or two coals are reported. These are very near the horizons of the Lower Freeport, Middle Kittanning, and Lower Kittanning. The Butler sandstone overlies the highest bed. At Sewickley, a few miles below Pittsburg, Doctor White measured the core of a diamond drill and recognized the Upper and Lower Freeport, the Upper and Lower Kittanning, all very thin and no limestones present.†

A record in northwest Westmoreland shows coals at 44, 127, and 218 feet below the Upper Freeport. Four miles east from this locality Mr W. G. Platt found the Lower Freeport, Lower Kittanning, and Brookville coals at 30, 110, and 217 feet below the Upper Freeport. The agreement is sufficiently close for correlation between the ordinary record and a measured exposure. On the Pennsylvania railroad at Carpenter station the only coals are the Upper Freeport and one at 199 feet lower, which may be the Clarion. Farther south, at Sewickley, the Lower Free-

* J. J. Stevenson: Fayette and Westmoreland (K K), pp. 82, 141, 159, 160, 167, 171, 186, 193, 319, 320.

† J. F. Carll: (I 5), pp. 251-256.

I. C. White: Bulletin no. 65, p. 112.

port and Middle Kittanning are reported, 70 feet apart, with almost continuous sandstone below the latter to the Pottsville.*

Records referred to a definite datum in Fayette county are confined to the southern portion of the county. Mr Campbell gives three which may be cited. In the Mach well the Upper Freeport horizon is marked by 14 feet of shale and coal, the Kittanning sandstone is 49 feet thick and rests on 16 feet of "shale and coal" marking the Clarion-Brookville horizon. Near the Monongahela river, on Cats run, there is no coal in the Allegheny. At a few miles south the first coal bed is very near the place of the Upper Kittanning, and at 65 feet below it is the Kittanning sandstone, 87 feet thick and reaching down to the representative of the Clarion-Brookville, which rests on the Pottsville.†

On the west side of the Monongahela river the section may be followed through Washington and Greene counties of Pennsylvania and the northern "panhandle" of West Virginia, lying between those counties and the Ohio river.

At McDonald station, near the northern line of Washington, the coal beds, all insignificant, are the Lower Freeport, Middle and Lower Kittanning, and the Brookville, the relations being as at Sewickley and Pittsburg. The thickness of the Allegheny is not determinable, but is between 255 and 275 feet. The only recognizable sandstone is the Kittanning. At Washington the Upper Freeport is 548 feet below the Pittsburg, there being a distinct thinning in the lower portion of the Conemaugh, and the Allegheny is 285 feet thick. The only coal bed reported is at 153 feet below the place of the Upper Freeport and represents one of the Kittannings. The Butler and Freeport sandstones are one, 75 feet. This sandstone is present in West Finlay and Mount Pleasant townships, but the records show no coal in those or in Amwell township. Nearer the Monongahela two thin coals are reported, but their relations are obscure. It should be remembered that thin black shale is likely to be reported as coal by the drillers.‡

Passing over into Brooke county of West Virginia, one has at New Cumberland Doctor White's section:

	Feet.	Feet
1. Ames limestone		
2. Interval		236
3. Mahoning coal bed [Brush Creek]		4
4. Interval		90
5. Lower Freeport coal bed	2 to	3

* J. F. Carll: (I 5), pp. 221, 225; 1886 Rept., p. 728.
W. G. Platt: (H 5), pp. 6, 27.
† M. R. Campbell: Masontown-Uniontown folio, pp. 18, 19.
‡ J. F. Carll: (I 5), pp. 302, 306, 307, 318; 1886 Rept., pp. 758, 765.
I. C. White: Bulletin no. 65, p. 113.

	Feet.	Feet
6. Interval		100
7. Middle Kittanning		Blossom
8. Interval	20 to	30
9. Lower Kittanning coal bed		Blossom
10. Fireclay		10

The interval from the Ames limestone to the Lower Freeport is 340 feet, whereas at Smiths ferry, 10 miles northeast, it is 366 feet; but the distance from Ames to Lower Kittanning has diminished not more than 3 or 4 feet. The Brush Creek coal bed is the Groff vein coal 7 of the northern Ohio column. Ten miles farther south, opposite Steubenville, Ohio, the Lower Freeport coal bed has been mined. No measurements are available on the West Virginia side of the river, but on the Ohio side the interval to the Ames limestone is 340 feet, which, as appears from many measurements by Newberry, Orton, and Stevenson, is 210 to 220 feet below the Pittsburg coal bed—a notable decrease in the upper part of the Conemaugh, which must be kept in mind. Direct measurement at Steubenville shows the interval to the Pittsburg 550 feet. There the Upper Freeport is present at 42 feet above the Lower and very thin.

At Wellsburg, in Hancock county, 10 miles farther south, this Lower Freeport coal bed is 320 feet below the Ames and 540 feet below the Pittsburg, with a 40-foot sandstone at 70 feet below it. From the Pittsburg to the Pottsville at Wellsburg is only 739 feet, whereas at McDonald, 15 miles east-northeast, it is about 880 feet, there being loss in both Conemaugh and Allegheny, so that the latter is not far from 200 feet thick in this area. No coal, aside from the Lower Freeport, is noted in the Wellsburg record, but Doctor Newberry found thin lower coals on the Ohio side where the Lower Freeport limestone is persistent. Wheeling, in Ohio county, is about 10 miles south from Wellsburg and about 20 miles west from Washington, in Pennsylvania. Three miles east from that city a record shows 4 feet of coal at 530 feet below the Pittsburg and resting on sandstone, thus:

	Feet
Gray sandstone	45
Coarse gray sandstone	83
Fine white sandstone	408
Gray and white sandstone	170

this sandstone being continuous to the bottom of the Logan. The mass number 3 is apparently homogeneous and the change to number 2 is so marked that the upper 128 feet may be allotted to the Allegheny. The coal bed at 530 is very probably at the Upper Freeport horizon, for the Lower Freeport in the Wheeling well is at 556 feet. This interval of 26 feet is that between the Freeports at a little way north, where Professor

Orton found it varying from 26 to 42 feet within a short distance. The Wheeling record shows two coals, one at 556 and the other at 96 feet lower, resting on 541 feet of sandstone. The lower bed is clearly the Lower Kittanning, the "Clay vein" of the Ohio side, which at exposures up the river is from 100 to 115 feet below the Lower Freeport. This lower bed, the Lower Kittanning, appears in another well on Wheeling creek at 645 feet below the Pittsburg.

Southward, in Marshall county, west from Greene county of Pennsylvania, the record of a well at about 7 miles south from Wheeling shows the "Big lime" of the Lower Carboniferous only 983 feet below the Pittsburg. The top of the Pottsville seems to be at 780, but it is probably higher, the upper portion being shale. The Allegheny shows neither coal nor sandstone. Near Moundsville, 10 miles south from Wheeling, one finds a condition which will be observed many times farther south in Wetzel county of West Virginia, where in a considerable area only sandstone is found in the Allegheny. In one well near Moundsville sandstone begins at 615 feet below the Pittsburg and is continuous for 255 feet, and the "Big lime" is reached at 937. At 5 miles east from Moundsville the sandstone begins at 448 and is continuous to 748 feet below the Pittsburg, the "Big lime" being 958 feet. At Majorsville, in the northern part of the county, on the Pennsylvania line, 12 miles southeast from Wheeling, the interval to the "Big lime" has increased to about 1,100 feet, the Lower Freeport coal bed is at 593 feet, and the Allegheny consists of alternating shales and sandstones. Five miles farther south, near Loudensville, the only coal bed is at 615, and at 40 feet lower is a sandstone 70 feet thick. The relations of this bed are doubtful. It is too high for the Lower Kittanning and too low for the Lower Freeport. In the southern part of the county, on this side, the records give few details, only the sandstones being recorded; but in many wells sandstone predominates in the Allegheny. In one it begins at 640 and is continuous to 960; in another from 566 to 881, and in a third from 450 to 845 feet below the Pittsburg; but in other wells shales predominate to 690, 735, and 743 below that coal. These records are all from a single district extending five miles north from the line of Wetzel county.*

Returning to Pennsylvania, one finds a record at Nineveh, in Greene county, almost at the Washington line and about 12 miles east from Majorsville. Here the Allegheny shows neither coal nor black slate and no important sandstone except the Butler-Freeport, 70 feet thick. In

* I. C. White: Geology of West Virginia, vol. i, pp. 350, 352, 363, 365-366; vol. ia, pp. 218-219, 220, 223-224, 228, 231; vol. ii, pp. 460, 464-465.
J. S. Newberry: Ohio Survey, vol. iii, pp. 741, 760.
E. Orton: Vol. vi, p. 61.

central and eastern Greene sandstones are as marked as those in the West Virginia "panhandle." Two miles east from Waynesburg, in the central part of the county, 12 feet of sandstone is reported at 620 feet below the Pittsburg, resting on 370 feet of black slate extending into the Pottsville; at 5 miles east, the bottom of the Mahoning interval is reached at 575, and at 607 this succession begins:

	Feet
Dark sand	58
White sand	390
Dark sand	80

in all, 528 feet of sandstone. No coal is reported. At 4 miles southeast from the last the sandstone begins only at 691 and there is no coal above it. Twelve miles southeast from Waynesburg, at Willow Tree, the only coal bed present is about 830 feet below the Pittsburg, evidently at the Brookville-Clarion horizon. Several miles southwest from Waynesburg the Upper Freeport is at 555 feet below the Pittsburg, and in the succeeding 325 feet there are 250 feet of sandstone, and much of the shale is sandy. No other coal is reported.

Doctor White gives many records in western Greene county, but they are not in detail; they suffice, however, to show that the Allegheny contains no great sandstones in that area.*

OHIO

Doctor White's series of vertical sections connect Pennsylvania with Ohio. The relations of the beds within the latter state were worked out by Professor Orton, whose discussion of the Ohio Lower Coal Measures must always remain preeminent not only for scientific accuracy, but also for the delicacy with which are corrected the errors into which the inexperienced observers of the Second survey fell.

Mahoning county adjoins Lawrence of Pennsylvania. Doctor White's section at Lowellville, one mile west from the state line, is:

	Feet.	Feet.	Inches
1. Kittanning [Lower] coal bed		2	4
2. Concealed		40	0
3. Ferriferous [Vanport] limestone	10 to	18	0
4. Argillaceous shale		2	6
5. Scrubgrass coal bed		0	6
6. Sandy shales		12	6
7. Clarion coal bed		1	4
8. Flaggy sandstone		17	0
9. Brookville coal bed		0	10
10. Homewood sandstone			

* J. F. Carll: Seventh Rept. on Oil and Gas (I 5), pp. 310, 313, 341-347.
I. C. White: Geology of West Virginia, vol. *ia*, pp. 123, 131.

The Homewood sandstone has become very thin, so that the Vanport limestone is but 80 to 110 feet above the Upper Mercer limestone, the variation being chiefly below the Brookville coal. The Vanport, so important in western Pennsylvania, quickly becomes uncertain in Ohio, though its horizon is recognizable at many places by means of calcareous sandstone or shale or even impure limestone; but its office as stratigraphical guide is performed by a new limestone, the Putnam Hill of Andrews, Gray of Newberry, which makes its appearance at Youngstown, 9 miles west from the state line, where it is 2 feet 7 inches thick. This, immediately overlying the Brookville coal bed, is from 15 to 50, but ordinarily about 30 feet below the place of the Vanport. In southern Mahoning Professor Orton found the Lower Kittanning at 48 feet above the Vanport limestone, which is represented by "chip slate, calcareous nodules, and cone-in-cone," the last being a characteristic feature of the bed wherever degenerate in western Pennsylvania. Here it overlies the Scrubgrass (locally Canfield) coal bed, which is double throughout this area, the upper division often cannel. It is about 150 feet below the Upper Freeport, or White limestone of Newberry.*

Columbiana county is south from Mahoning. A boring at Leetonia, 2 or 3 miles south from the Mahoning line, shows the Lower Kittanning (locally Leetonia) coal bed at 47 feet above the Scrubgrass (Upper Clarion). The Clarion coal bed is at 28 feet lower and 11 feet 6 inches above the Putnam Hill limestone. The Lower Freeport coal bed, with its underlying limestone, is in the Leetonia hills at 75 feet above the Lower Kittanning, and the Freeport sandstone occupies most of the interval. The section is very like that at Lowellville, except that the Vanport limestone has disappeared. At New Lisbon, 6 or 8 miles farther south, the top of the Allegheny is reached and the Vanport limestone reappears; the intervals are:

	Feet.	Inches
Upper Freeport	3	4
Interval	22	0
Lower Freeport	1	0
Interval	87	0
Middle Kittanning	0	8
Interval	12	0
Lower Kittanning	1	4
Interval	40	0
Vanport limestone	3	0
Scrubgrass and parting	9	0

* J. S. Newberry: Ohio Survey, vol. iii, p. 803.
I. C. White: Pennsylvania report (Q Q), pp. 219, 222.
E. Orton: Ohio Survey, vol. v, pp. 20, 31, 33.

The Freeport limestones are present, as are also the Butler and Freeport sandstones. The interval from the Lower Kittanning to the Scrubgrass is almost the same as at Leetonia, while that from the Upper Freeport to the Lower Kittanning is 162 feet, practically the same as in southern Mahoning, where it is 150 feet from the Upper Freeport limestone. The Lower Freeport becomes locally important as the Whan coal bed within a small area in central Columbiana, but for the most part it is worthless.

The Upper Freeport coal bed is wanting in most of Doctor White's sections in eastern Columbiana, but its limestone is present at 40 to 45 feet above the Lower Freeport. The Middle Kittanning (Darlington) is present to nearly midway in the county, but the Vanport limestone is of uncertain occurrence, at times represented only by fossiliferous shale. In the southern part of the county, Doctor Newberry reports the Lower Kittanning as 115 to 125 feet below the Lower Freeport, and at Liverpool 176 feet below the Upper Freeport.*

Farther south, on the north border of Jefferson county, the section to the Lower Kittanning is shown at several places. Professor Orton gives two measurements on Yellow creek, three miles apart:

	Feet.	Inches.	Feet.	Inches
Brush Creek coal bed	4	6	4	0
Interval with Mahoning limestone	60	0	67	0
Upper Freeport, "Big vein".......	Blossom		4	0
Interval with Upper Freeport limestone	72	0	61	0
Lower Freeport, "Roger vein".....	Blossom		3	0
Interval with Lower Freeport limestone	65	0	65	0
Middle Kittanning, "Darlington"..	Blossom		2	4
Interval with thin coal...........	23	6	22	0
Lower Kittanning, "Creek clay," or "Potters' vein".............	Blossom		2	0

The Ames limestone is 220 feet above the Upper Freeport near the second measurement. Professor Orton says that the Pittsburg is about 530 feet above the Lower Freeport and the Ames is 260 above the Upper Freeport near the first measurement, a loss of almost 50 feet in 14 miles from Smiths ferry. Southward from Yellow creek the Upper Freeport becomes uncertain and the Lower Freeport, hitherto irregular, becomes very important. The Lower Kittanning, exposed along the river for more than 10 miles below Yellow creek, is accompanied by its important clay bed. The interval between the Lower Freeport and Lower Kittanning is

* I. C. White: (Q Q), pp. 266, 272, 274.
J. S. Newberry: Vol. iii, pp. 108, 113-115.
E. Orton: Vol. v, pp. 37-38.

given to abrupt variations; within a distance of 8 miles below Yellow creek it is 89, 120, and 86 feet. The Vanport limestone seems to be represented at Elliottsville by 3 feet 6 inches of fossiliferous shale at 26 feet below the Lower Kittanning, and the Putnam hill limestone by 5 feet of fossiliferous limestone and slate at 28 feet lower. Underneath the last is the Brookville coal bed, 6 inches, resting on 10 feet of black slate. The Scrubgrass seems to be represented by black shale under the Vanport. The Upper Freeport limestone is persistent in most of the sections where its horizon is reached, but the place of the coal is occupied in some sections by a buff limestone overlying the non-plastic clay marking the horizon. At Steubenville the Lower Freeport or "Shaft coal" is 547 to 551 feet below the Pittsburg, 327 to 331 feet below the Ames limestone. The Lower Kittanning has been found at 80 to 98 feet lower in borings and the Brookville is reached in one boring at 40 feet below the Lower Kittanning. At La Grange, opposite Wellsburg, in West Virginia, the Pittsburg is 540 feet above the Lower Freeport, which is 5 feet 3 inches thick, and at 22 feet above it is a double bed, representing the Upper Freeport. The lower bed retains its thickness farther down the river, where it is 7 to 8 feet thick and good.*

Returning to the northern outcrop, one finds the Putnam Hill limestone extending into Portage county, west from Mahoning, where it overlies the Brookville coal at many places.†

Stark county, south from Portage, is west from Mahoning and Carroll. Newberry's generalized section for the county is:

	Feet.		Feet
1. Shale and sandstone	30	to	50
2. Buff limestone and ore	0	to	6
3. Black band ore	0	to	10
4. Coal 7 [Upper Freeport]	1	to	3
5. Fireclay	..		1
6. Shale and sandstone, with thin coal near middle	75	to	110
7. Coal 6 [Middle Kittanning]	2	to	6
8. Fireclay and shale	42	to	65
9. Coal 5 [Lower Kittanning]	2	to	3
10. Fireclay, shale, sandstone	42	to	65
11. Putnam Hill limestone	0	to	4
12. Coal 4 [Brookville]	3	to	6
13. Fireclay	1	to	3

the last being 20 to 50 feet above the Lower Mercer, or Zoar, limestone.

* J. S. Newberry: Vol. iii, pp. 103, 757, 758, 760.
E. Orton: Vol. v, pp. 50-51, 53, 55-57, 59, 61.

† J. S. Newberry: Vol. iii, pp. 137, 142.

The Putnam Hill and Brookville coal are termed the "Upper limestone and coal." The coal has been mined at many places; it is best in the northern part, but deteriorates in quality toward the center of the county, sulphur and ash increasing; toward the south it becomes variable in thickness as well as quality, 1 to 7 feet; sometimes cannel, at others slaty; at times caking, at others open-burning coal. Professor Orton recognizes the Vanport in eastern Stark where a calcareous sandstone is at 30 feet above the Putnam Hill. There the Lower and Middle Kittanning are only 15 to 18 feet apart. A thin coal, marking the Clarion horizon, is seen occasionally above between the Putnam Hill and Lower Kittanning. The Lower Kittanning, usually thin but attaining 4 feet in the eastern part of the county, is accompanied by its clay and is as truly the "clay vein" here as on the Ohio river. The roof is black shale with iron ore. The Middle Kittanning, usually about 50 feet above the Lower, is 4 to 6 feet thick in the southern part of the county, but is thinner toward the north, where it becomes unimportant. The Upper Kittanning is evidently absent and the Lower Freeport is a mere blossom. The Upper Freeport is unimportant, but it is accompanied by the overlying ore which marks the horizon in several counties south and east from Stark. Professor Orton discovered the Freeport limestones in eastern Stark, but elsewhere they were not found. The sandstones are very irregular; occasionally they appear in the Freeport and Kittanning intervals, but the change into shale is abrupt.*

Carroll is between Stark and Tuscarawas at the west and Columbiana and Jefferson at the east. The Freeport coals, both thin, have been opened in the northwest townships, and the upper bed is accompanied by its underlying limestone and overlying ore. Eastward the Upper Freeport becomes important; it can be followed from Yellow creek, in Columbiana county, somewhat decreased in thickness, but in the southern part of the county it is often 4 feet 6 inches and yields good coal. The chief drawback is the frequency with which it is cut out by the overlying sandstone, and these "wants" are so common in some areas that mining operations have been abandoned. The Lower Freeport is persistent, but usually too thin to be utilized. It is rarely more than 30 feet below the Upper. The Upper Freeport limestone is present at almost all localities where its place is exposed.†

Harrison county is south from Carroll and east from Tuscarawas. The section reaches to the Lower Freeport, but that and the Upper Freeport

* J. S. Newberry: Vol. iii, pp. 155, 168-169, 170, 171-176.
E. Orton: Vol. v, pp. 66, 70-72.

† E. Orton: Vol. v, pp. 72-73, 77-78, 246-247, 254-255.

are exposed only in the northwest corner of the county; elsewhere they are buried under the Conemaugh and Monongahela. Professor Bownocker gives the record of a well in the eastern portion in which a coal bed is reported at 592 feet below the Pittsburg. It is not altogether easy to determine the place of this bed, but it is very near the place of the Brookville. That coal bed at Steubenville is 673 feet below the Pittsburg, but in this portion of Harrison the interval from Pittsburg to Ames limestone is 85 feet less than near Steubenville, so that the interval to this bed is within 4 or 5 feet of what should be expected.*

Tuscarawas county, south from Stark, is west from Carroll and Harrison. The section in the northern portion differs extremely from that in the southern, but they are connected by intermediate sections showing the gradual change. Full sections have been measured by both Professor Newberry and Professor Orton in the critical localities and their records are in practical agreement, the differences being due apparently to variation in barometric readings. The sections by Newberry are as follows, one at the north and the other at the south:

	Feet.	Inches.	Feet.	Inches
1. Sandstone [Mahoning]	60	0	30	0
2. Shale	12	0	10	0
3. Mountain ore	0 to 5	0	0	0
4. Black band	3 to 8	0	0	0
5. Coal 7 [Upper Freeport]	3	0	4	0
6. Interval	70	0	35	0
7. Coal 6*a* [Lower Freeport]	Thin	..	2	0
8. Conglomerate, sandstone, shale [Freeport]	50	0	52	0
9. Coal 6 [Middle Kittanning]	4	0	4	0
10. Shale and fireclay	33	0		
11. Impure cannel	1	0	29	0
12. Fireclay and dark shale	26	0		
13. Coal 5 [Lower Kittanning]	2	0	2	6
14. Fireclay	4	0	10	0
15. Shale and sandstone	50	0	79	0
16. Putnam Hill limestone	3	0	1	0
17. Coal 4 [Brookville]	2	0	5	0

with to the Zoar limestone an interval of 53 and 46 feet respectively. The Brookville, as a rule, is slaty and sulphurous, with a tendency to become cannel; ordinarily thin, it becomes 5 to 6 feet thick in the southern part of the county, but with no improvement in quality. The Putnam Hill limestone carries ore, is flinty, and rich in fossils. The Lower Kittanning, important in the eastern part, is uncertain, often wanting in the western part, as in Carroll county, and the coal exhibits notable

* J. J. Stevenson: Vol. iii, p. 203.
J. A. Bownocker: Bulletin no. 1, p. 231.

variations in ash and sulphur. The underlying clay retains its importance, is often non-plastic, and is utilized in manufacture of firebrick. The interval to the Middle Kittanning varies from 50 feet in the northern portion to 20 and 30 feet in the southern part of the county. Near Zoar, on the northern border, a cannel 1 foot to 18 inches is at 16 to 26 feet above the Lower Kittanning, but it is wanting southward. The Middle Kittanning, as in Stark, is important and is the Coal 6 of central and southern Ohio. It is from 3 feet 6 inches to almost 6 feet thick, and, while varying somewhat in quality, it is usually good, always caking, though generally containing too much ash for a good merchantable coke without washing. As a rule, it is double, with a copperas band at about a foot from the top. The roof is a black shale, often carrying "large calcareous nodules or concretions, filled with beautifully preserved Coal Measure fossils" and at times becoming bony cannel in the lower portion. The bed identified with the Lower Freeport is indefinite and the accuracy of the correlation is open to question, at least for the northern part of the county. The Upper Freeport is persistent, rarely yields good coal, and is double, the parting varying from 8 inches to 15 feet. This characterizes the bed in Guernsey county.

The Vanport limestone reappears in many sections and is fossiliferous; it is seen occasionally midway in the county, but more commonly in the western portion, where the Lower Kittanning coal bed is wanting.*

Guernsey county, south from Tuscarawas, shows the whole Allegheny section in the western portion. The Upper Freeport coal bed is 200 to 255 feet below the Ames limestone. The Cambridge limestone of the Conemaugh becomes characteristic here and is an important stratigraphical guide southward. Professor Orton's section in northwestern Guernsey is:

	Feet.	Inches
1. Cambridge limestone	2	0
2. Interval	111	0
3. Upper Freeport coal bed [Cambridge]	Thin	
4. Clay, Upper Freeport limestone	10	0
5. Interval	50	0
6. Lower Freeport coal bed	Thin	
7. Interval	100	0
8. Middle Kittanning	3	0
9. Fireclay and shale	30	0
10. Lower Kittanning	2	6
11. Fireclay	20	0
12. Interval	16	0
13. Putnam Hill limestone	4	0
14. Brookville coal bed	Thin	

* J. S. Newberry: Vol. iii, pp. 61-62, 64-66, 67-70.
E. Orton: Vol. v, pp. 92-93, 268, 274, 279, 282.

The Upper Freeport coal bed is from a few inches to 5 feet or more in thickness, the variations being so great that the bed is only locally important. The Lower Freeport is unimportant. A thin coal was seen at a little way northeast from the village of Cambridge, which Professor Orton is inclined to refer to the Upper Kittanning. The Middle Kittanning shows its characteristic roof, in which the nodules often contain a nucleus of sphalerite. The coal is good enough for local use and the bed is 3 to 4 feet thick. The Lower Kittanning is accompanied by its fireclay. The Brookville varies from 18 inches to 5 feet and yields poor coal. The interval to the Middle Kittanning in one township is only 26 feet, the Putnam Hill limestone being present.*

In Belmont county, east from Guernsey to the Ohio river, the Allegheny is deeply buried. No information is available for this county aside from the record of a well in Washington township 3 or 4 miles from the river, which shows only shales for 750 feet below the Pittsburg coal bed to a great sandstone which belongs to the Pottsville.†

Returning to the west: In Wayne county, west from Stark, Mr Read identifies with Coal 6, the Middle Kittanning, a bed only 25 to 30 feet above the Gray or Putnam Hill limestone. It is 2 to 4 feet thick, with black lustrous caking but sulphurous coal. It has the characteristic roof, black fossiliferous shale. The Brookville coal bed underlies the limestone and is 2 to 4 feet thick, sometimes cannel and generally slaty and sulphurous. The Freeport sandstone was seen at one locality 25 feet thick and, as in parts of Stark, Tuscarawas, Carroll, and Harrison, very coarse or finely conglomerate.‡

Holmes county is south from Wayne and west from Tuscarawas. Professor Wright's generalized section for the county is:

	Feet
1. Upper Freeport coal bed (7)	
2. Shaly sandstone	30
3. Lower Freeport coal bed (6*a*)	
4. Freeport sandstone	45
5. Middle Kittanning coal bed (6)	
6. Shale and iron ore	25
7. Lower Kittanning coal bed (5)	
8. Sandy shales	20
9. Ferriferous limestone [Vanport]	
10. Clarion coal bed	
11. Sandstone and shale	25

* E. B. Andrews: Vol. ii, p. 538.
J. J. Stevenson: Vol. iii, pp. 223-224, 231.
E. Orton: Vol. v, pp. 82, 89, 283-285, 289.
† J. A. Bownocker: Bulletin no. 1, p. 220.
‡ M. C. Read: Vol. iii, pp. 531, 535.

	Feet
12. Putnam Hill limestone	
13. Brookville coal bed	
14. Tionesta sandstone [Homewood]	20

The Brookville coal and its overlying limestone are present in perhaps every township; the coal, according to Professor Wright, is from 1 to 2 feet thick and always poor; Mr Read found it 3 feet 6 inches at one locality. The Vanport is present as a gray limestone at several localities, but in some townships it is represented only by tough more or less flaggy sandstone. A Clarion coal bed underlies this limestone at many places, usually very thin and never exceeding 2 feet. From the observations of both Read and Wright, it is clear that the Lower Kittanning is present only in the southeasterly part of the county, and that westward and northward the interval between it and the Middle Kittanning disappears, permitting, as suggested by Professor Wright, the two beds to come together. In the southeast the Middle Kittanning is 64 feet above the Clarion coal and 83 feet above the Putnam Hill limestone, but on the western border the interval to the limestone is but about 35 feet at the most and to the Clarion only 22 feet. The interval in Wayne county between Middle Kittanning and Putnam hill increased southwardly from 25 to 35 feet and the increase is continuous and gradual to southeast Holmes. The Middle Kittanning is the important bed and shows the same features as in Tuscarawas—double, with sulphur near the top, the coal coking, ash purple, and the roof bone or cannel underlying the richly fossiliferous black shale. The Freeport sandstone is massive; the Lower Freeport is but a blossom. Mr Read states that the upper Freeport, 4 to 6 feet thick, is present on the western border at only 40 feet above the Middle Kittanning and accompanied by a buff limestone. In the southern part of the county the interval is 73 to 76 feet. Mr Read reports a black limestone in the eastern part of the county at 12 to 15 feet above the Brookville.*

Coshocton county is south from Holmes and west from Tuscarawas and Guernsey.

The Brookville coal bed and Putnam Hill limestone persist throughout the county; the former is from a few inches to several feet thick, but it seldom yields good coal, being so broken by partings as to be dirty, but sometimes changing into cannel or cannel slate. At varying distances, 10 to 30 feet, above the Putnam Hill is the "Black marble" overlying a coal bed. Professor Hodge observed this limestone in five townships and

* M. C. Read: Vol. iii, pp. 554-555, 557-558.
A. A. Wright: Vol. v, pp. 818-819, 828, 830-831, 836, 839, 840-842.

in one the coal bed is 30 feet above the lower limestone. The place of this limestone, evidently the same with Read's black limestone of Holmes, is very uncertain, for it sometimes approaches very closely to the Middle Kittanning. It is not far from the place of the Lower Kittanning, which at one time was mined near Coshocton, where it is 30 feet below the Middle Kittanning and 44 feet above the Putnam Hill, and there the Marble is represented by a calcareous sandstone. The great variability of intervals in Coshocton county adds to the difficulty of correlating this limestone. As it overlies the coal, one may be justified in regarding it as representing the Vanport and the underlying coal as a Clarion bed; so that where it approaches closely to the Middle Kittanning the interval to and including the Lower Kittanning has disappeared as it does in Holmes county.

The Middle Kittanning, according to Professor Orton, Jr., is from 32 to 79 feet above the Putnam Hill limestone; there is no place for error in the small interval, for the section is distinct down to the Lower Mercer coal bed. The greatest interval was found near the Holmes line and the least at 8 or 10 miles south. Professor Hodge's sections show even greater variation in this interval. In the northeast corner it is 90 to 100 feet; 6 miles west it is 100; barely 6 miles farther west it is 40 to 50 feet; in the south central part of the county it is 46 to 65, but in the southern tier of townships along the Muskingum border it is 80 to 90 feet. There is no possibility of error in the identification, as the "Black marble," Putnam Hill, and Zoar (Lower Mercer) limestones are present in most of the sections and the Middle Kittanning shows the usual features throughout. The last is the important coal of the county.

Very little information is available for the higher beds. No trace of the Upper Kittanning appears.

Professor Hodge reports a 1 foot 6 inches bed at 90 feet above the Middle Kittanning, near the Holmes line, and in an adjoining township is a limestone at 65 feet above the Middle Kittanning. This may be the very fossiliferous buff limestone seen in Bedford township at 130 feet above the Putnam Hill limestone. A coal bed is in two townships at 60 to 70 feet above the Middle Kittanning and near Coshocton it is 87 feet. This bed, 60 to 90 feet above the Middle Kittanning, may be the Lower Freeport. The Upper Freeport, wholly unimportant, is reached in the northeastern part of the county, where Mr Hodge found it 115 feet above the Middle Kittanning and underlying ore and limestone as in Tuscarawas and Stark.*

* J. T. Hodge: Vol. iii, pp. 570-571, 573, 578-579, 580, 582, 586-587, 589, 591.
E. Orton: Vol. v, p. 93.
E. Orton, Jr.: Vol. v, pp. 855-857.

Muskingum county is south from Coshocton and west from Guernsey and Noble. In the northern part of the county Stevenson recognized both Freeport coals, the Middle Kittanning, and the Brookville. The last is persistent, usually an inferior cannel, and varying in thickness from 7 inches to 4 feet. The Putnam Hill limestone is often flinty and usually carries some ore, but no trace of the Coshocton "Black marble" appears in any of the sections. A coal bed appears in one township between the Middle Kittanning and the Putnam Hill limestone, 18 to 55 feet below the upper coal and it may be at the Lower Kittanning horizon; it certainly is wanting at many localities where the exposure of the interval is complete. The Middle Kittanning shows the same features as in Coshocton and is from 80 to 105 feet below the Upper Freeport. The latter bed is worthless except in the eastern side of the county, where it is mined. The interval to the Middle Kittanning increases eastwardly. The Freeport sandstone at times fills almost the whole interval to the Upper Freeport and occasionally is conglomerate.*

The section changes somewhat in the southern part of the county, for there the Upper Freeport and the Middle and Lower Kittanning coal beds are each of them important within circumscribed areas and the Brookville coal bed becomes irregular, being reported by Professor Andrews from only three townships. It certainly is absent in many places where the exposures appear to be complete. A coal blossom appears on top of the Putnam Hill limestone in one section at Zanesville and the Clarion coal is present at Zanesville as well as at some other places at varying distances above the Putnam Hill. The Vanport limestone is present at Zanesville as a nodular bed; elsewhere it was seen by Professor Orton, who describes it as drab, weathering yellowish white, fossiliferous, and associated with iron ore. It is very near the place of the Coshocton marble, which, according to Hodge, sometimes is drab and always is fossiliferous. It is at the place of the Lower Kittanning and is never seen in this county when that coal bed is present.

The Lower Kittanning is 65 feet above the Putnam Hill limestone at Zanesville, but the interval decreases southward to 38 feet at Del Carbo. Along this line the coal is from 3 to 5 feet thick and is mined; but southward within 2 or 3 miles it disappears, and the Vanport limestone reappears at 21 feet above the Putnam Hill; farther south on the Perry County line the coal is again present and mined. Eastward from this narrow area the bed is very uncertain. It is present in Washington township east from Zanesville, and again in Perry, where Andrews reports it as 2 feet thick and 3 feet above a sandy limestone and ore, evidently

* J. J. Stevenson: Vol. iii, pp. 247, 249, 250, 254, 258.

at the Vanport horizon. The Middle Kittanning is thoroughly persistent, though not always of workable thickness. It attains its chief importance along a narrow space southward from Zanesville to the Perry line, but eastward it becomes unimportant. It has the features already mentioned, but occasionally becomes triple. The Lower Freeport is reported as a blossom, but it is not always present, as sandstone often fills nearly the whole interval to the Upper Freeport. The Upper Freeport limestone is shown in many sections. The Upper Freeport coal, like the beds below, is good in the strip extending southward from Zanesville, where it is known as the Alexander coal and is about 4 feet thick, yielding a coal low in ash, though rather high in sulphur. Elsewhere for the most part it is very thin, though near the Guernsey border it sometimes is 3 feet. Everywhere it is somewhat uncertain; frequently the clay and limestone are present without any trace of coal; in others it is in patches, having been removed from intervening spaces during deposit of the overlying sandstone.*

Southward from Muskingum one enters Perry county and passes into the Hocking Valley coal field, embracing portions of Perry, Hocking, and Athens counties. This region was studied first by Professor Andrews, afterward by Mr Read, and finally the whole work was revised by Professor Orton.

Passing out of Muskingum county at Roseville, one soon reaches McLuney, in Perry, where the Upper Freeport is at 107 feet above the Middle Kittanning and is accompanied by the blackband ore which has been missing for nearly 50 miles, as the outcrop in the intervening space is too far east to catch it. Professor Orton observed long ago that the blackband is only on the border of the field, associated with thin coal, while toward the interior of the field the blackband diminished and the coal became thicker. Here the ore and coal are but 3 feet. At New Lexington, 8 or 9 miles southwest and beyond the final outcrop of the Upper Freeport, both Kittannings are mined and are from 20 to 30 feet apart, as in southern Muskingum. The Putnam Hill limestone is present here, limestone and flint, with the Clarion coal bed at 10 to 15 feet above it; but southward it changes and soon becomes worthless as a stratigraphical guide, its office in that respect being taken by the "Baird ore," 15 to 30 feet higher, the Ferriferous limestone of Andrews, the "Limestone ore" of the southern counties, which is very near the horizon of the Vanport limestone. Six miles farther south the Kittannings are both present, but the Lower is only 1 foot thick 15 feet above

* E. B. Andrews: Vol. i, pp. 320-321, 324-327, 330, 332, 334-335.
E. Orton: Vol. v, pp. 96-97, 99, 100, 878.

the Vanport and 34 feet above the Putnam Hill; thence the Middle Kittanning thickens rapidly and within 2 miles becomes the "Great vein" of Shawnee and Straitsville, 8 to 12 feet thick. The bed holds its thickness across Ward township of Hocking into York of Athens, where it is the Nelsonville coal, 6 to 10 feet thick; thence it decreases, so that in Waterloo township of Athens it is but 3 feet 6 inches and is known as the Carbondale or Mineral City seam. The Lower Kittanning appears in most of Professor Andrews's sections along this west side in Perry, Hocking, and Athens counties. The Vanport limestone with its ore is persistent and the Clarion coal bed is shown in some of the sections; but the Brookville, underlying the Putnam Hill limestone, is very indefinite south from the Muskingum line. The interval from Middle Kittanning to the Baird ore (Vanport) decreases from 45 feet at 6 miles south from the Muskingum line to 38 feet at Waterloo, in Athens county.

The higher members of the formation are followed without difficulty, but at some distance farther east. Several deep valleys on the west side of the field show the whole series, while Sunday creek, on the east side, shows the section down to the Lower Kittanning, in Monroe of Perry, Trimble, and Dover townships of Athens. Three sections suffice to exhibit the variations:

I. Moxahala, in Perry county (Read).
II. Shawnee, in Hocking county (Orton).
III. Nelsonville, in Athens county (upper part from Orton, lower by Read).

	I. Feet.	I. Inches.	II. Feet	II. Inches	III. Feet.
1. Upper Freeport	4	6	3	0	6
2. Interval	31	0	18	0	32
3. Limestone and ore	..	..	2	0	3
4. Interval	15	0	34	0	18
5. Lower Freeport	6	0	1	0	2
6. Lower Freeport limestone	41 (6–8)	0 (6–8)	0	6	1
7. Sandstone or shale			25	0	34 (7–8)
8. Shale			20	0	
9. Middle Kittanning	12	0	10	0	8
10. Interval	26	0	26	0	23
11. Lower Kittanning	3 to 5	0	3	0	4 to 8
12. Fireclay and sandstone or clay	9	0	12	0	15 to 35
13. [Vanport] ore and limestone	0	10	1	0	2 to 3

The Shawnee or Upper Freeport limestone is at 18 to 30 feet below its coal bed. It rarely shows any flint, but usually carries iron ore; it is buff on weathered surface, is non-fossiliferous, and is almost as useful

in carrying the section as is the Vanport, Cambridge, or Ames limestone. The Lower Freeport limestone, Norris and Snow Fork of Orton, rarely appears in the sections. The Freeport sandstone is conspicuous at the north, but becomes indefinite southward. The Lower Freeport coal is widespread, but varies greatly in thickness; it is the Black coal of New Lexington, the Fowler of Moxahala, both in Perry; it is the Juniper and Frank coal of Waterloo, in Athens, where it is 15 to 20 feet below the Shawnee limestone and 26 feet above the Middle Kittanning. The Upper Freeport coal bed, known as "Stallsmith," "Norris," and "Bayley's run," is mined at many places, but rarely attains commercial importance. Occasionally it is 4 to 6 feet thick, but in much of the area it is wanting and its horizon can be traced only by means of the Shawnee limestone. All of the coal beds in this field, except the Middle Kittanning, are irregular, but each is workable at some locality. The interval from the Upper Freeport to the Middle Kittanning varies from 107 feet in northern Perry to 76 feet in the southern part of the county. At Nelsonville it is 100 feet, and Andrews found it about 100 feet near Athens, in the central part of the county.*

Eastward between the Hocking valley and the Ohio are the counties of Morgan, Noble, Monroe, Washington, and Meigs, in which the Allegheny is very deeply buried. A few records of oil borings are available, which afford some scanty information.

Morgan county, south from Muskingum, east from Perry and Athens, is west from Noble and Washington. On the western border a well shows the Upper Freeport coal bed, 6 feet thick, at 70 feet below the Cambridge and 206 feet below the Ames limestone. It is persistent in this oil district. The wells go no deeper. Midway in the county, at McConnellsville, a coal bed is reported at 347 feet above the Maxville limestone ("Big lime") and underlying a sandstone 44 feet thick. As the Pottsville is very thin here as compared with counties farther east, this may be Upper Freeport. It is only 276 feet from the surface, where the horizon can hardly be much more than 100 feet below the place of the Pittsburg, if Professor Andrews be accurate in his identifications.†

Noble county, south from Guernsey and east from Morgan, affords no information. A well in the extreme southern part, near Macksburg, has three coal beds at 339, 383, and 438 feet below the Ames limestone, the lowest bed being about 640 feet below the place of the Pittsburg; it is 730 feet below the Meigs coal, which is from 80 to 100 feet above the

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* M. C. Read: Vol. iii, pp. 665, 679, 705.
E. Orton: Vol. v, pp. 101, 108, 112.
E. B. Andrews: Rept. for 1869, plate of grouped sections.

† J. A. Bownocker: Bulletin no. 1, pp. 142, 145.

Pittsburg. It is not easy to correlate the higher beds, all of which are below the Upper Freeport, but the bottom bed is very near the place of the Brookville.*

In Monroe, east from Noble, the available records are better than in the counties referred to. This county, south from Belmont, extends eastward from Noble to the Ohio river, there adjoining Wetzel and Tyler counties of West Virginia. In the northwestern corner, within Summit township, only 6 or 8 miles south from the Belmont line, a record shows the Pittsburg present, though very thin. Sandstone begins at 453 feet below that coal bed; it is 45 feet thick and possibly is in part Mahoning. A great sandstone, at top the Butler-Freeport, begins at 10 feet lower and is almost continuous to 678 feet, where it overlies a coal bed, the same with that seen about 20 miles to the southwest at 640 feet. The Conemaugh thickens rapidly for a few miles from the western outcrop in Guernsey and Muskingum and its bottom in this region is not far from 480 to 490 feet below the Pittsburg. The Brookville is recorded again in Perry township, where, as in Summit, it is 350 feet above the Maxville or "Big limestone," but the interval to the Pittsburg is 705 feet, showing an increase in the Conemaugh. The interval remains constant for a considerable distance eastward, for in a well on the Ohio river the Pittsburg is 1,050 feet above the Maxville; but the Brookville coal is not recorded; that bed, however, is present beyond the river, in Tyler county, at 704 feet below the Pittsburg.†

Washington is south from Monroe and Noble and east from Morgan. The intervals are greater here than on the western outcrop. At Macksburg, in the northern part of the county, toward the Morgan border, the great sandstone below the Brookville is at 760 feet below the Meigs (Macksburg) coal bed, but the Brookville coal is not recorded; all coals seem to be wanting. The sand at the Butler-Freeport horizon is 78 feet thick and is known locally as the Dunkard; its top is about 460 feet below the place of the Pittsburg. Farther southeastward, in the Cowrun region, one finds the Monroe interval again. At Macksburg the Ames is about 190 feet below the Pittsburg; on Cowrun the exposures make it about 230 feet. In the Centennial well on Cowrun the Brookville is at 701 feet below the Pittsburg, with another coal at 63 feet higher; near Macksburg the next coal is 65 feet above the Brookville. The Allegheny shows in all only 66 feet of sandstone; but it is worthy of note that here, as in the West Virginia counties east from Washington,

* J. A. Bownocker: Bulletin no. 1, p. 160.

† J. A. Bownocker: Bulletin no. 1, pp. 196, 212, 216.
I. C. White: Geology of West Virginia, vol. i, p. 356; vol. ii, p. 391.

the red beds reach down into the Allegheny, for beginning at 503 feet below the Pittsburg is a great mass of red shale 64 feet thick and extending to the Kittanning horizon. In the same region Professor Andrews reports the Brookville coal bed at about 688 feet below the Pittsburg, but the interval from the Pittsburg to the well curb was not measured carefully and the difference in interval may be apparent, not real. Several miles farther south and near the Ohio the interval seems to be about 713; the measurement is approximate, but the increase is to be expected in this direction. At Marietta, 6 miles west from the last, the interval seems to be somewhat less than 725 feet, as will be seen in the discussion of the Conemaugh of this region. It is worthy of note here that in Monroe and Washington the Brookville is the only persistent coal horizon.*

Meigs county is south from Washington, along the Ohio river. Here also, for the most part, the Allegheny is deeply buried and the exposures rarely go down to the Upper Freeport, even in the western part of the county, where that coal bed is at 112 feet below the Upper Cambridge, about 85 feet below the Lower Cambridge limestone. The only available record is at Pomeroy, on the Ohio river, where the Cambridge limestone, apparently the Lower, is at 285 feet below the Pittsburg (Pomeroy) coal bed, about 40 feet more than at 6 miles west. The bottom of the Mahoning is at 431 feet, and at 15 feet lower begins a sandstone 58 feet thick. The first coal bed is at 529 feet below the Pittsburg, the second at 580, and the third at 675 feet. The first is at 210 feet below the Cambridge limestone. The lowest coal at 390 feet below the Cambridge is 10 feet above a massive pebbly sandstone, 62 feet thick, separated by 7 feet of shale from another thick sandstone, in which the well was stopped. This bottom bed appears to be the Brookville, as the interval from Pittsburg to Cambridge is fully 40 feet less than at the exposures east from Marietta, where the interval to the Ames is about 230 feet. Excepting that at 529 feet, the coals in the Pomeroy well are indefinite, being mere streaks distributed through 11 feet of shale, so that the condition at Letart, 10 miles east, in Mason county of West Virginia, is that to be expected, for there the coals are wholly absent from the Allegheny.†

Returning to the western outcrop and entering Vinton county, south from Hocking and west from Athens, one reaches the "Hanging Rock" district, embracing portions of Vinton, Jackson, Scioto, Athens, Gallia, and Lawrence counties, to the southern boundary of Ohio. In this nar-

* E. B. Andrews: Vol. ii, pp. 497, 502.
E. Orton: Vol. vi, p. 399.
J. A. Bownocker: Bulletin no. 1, pp. 161, 169, 176.

† E. Orton: Vol. vi, p. 397.

row area one has the detailed measurements by Professor Andrews, supplemented by Professor Orton's close revision, made ten years later, as well as local contributions by Messrs McMillin, Bownocker, and I. C. White. Throughout most of the area the main stratigraphical guides persist, though n some portions the Ames limestone of the Conemaugh becomes shale and the Putnam Hill limestone for the most part can be followed only with uncertainty. The several coal beds are present with more or less regularity, but each of them seems to be absent from considerable areas.

In Vinton county the Upper Freeport is often absent, and when present is so thin that it appears only as a "blossom" in Professor Andrews's sections; but its place is followed easily by means of its clay and the underlying limestone, here known as the Shawnee or Buff limestone. The interval to the limestone varies from 18 feet on the northern edge of the county to 58 feet at 18 miles south, and in this distance the interval from Upper Freeport to Middle Kittanning increases from 90 to 116 feet. The Lower Freeport coal bed does not appear in any of the sections by Andrews and its existence here is uncertain. At one time the important coal bed at Hamden furnace was thought to be at this horizon, but closer study proves it to be the Middle Kittanning. That bed is present throughout, though variable and decreasing in importance southward. It is from 18 to 50 feet above the Lower Kittanning, which is present in most of the sections, though seldom more than 2 feet thick. The least interval is in the northern part of the county, but in the southern townships it rarely exceeds 25 feet. The Lower Kittanning is 10 to 20 feet above the Vanport limestone and ore, below which, at 3 to 15 feet, is the Clarion or "Limestone bed," which is persistent, triple, and 2 to 4 feet thick. The Brookville—25 to 37 feet according to Andrews, 30 to 50 feet according to Orton—below the Clarion, is usually present and is workable in four townships, yielding a good coal, though rather high in ash and sulphur. Its thickness is from 2 feet 6 inches to 6 feet 7 inches.*

In Jackson county, south from Vinton, the complete section is shown on the Gallia border, thus:

	Feet.	Inches
1. Upper Freeport		
2. Sandstone	50	0
3. Lower Freeport	4	0
4. Interval	30	0
5. Sandstone	25	0

* E. B. Andrews: Vol. i, pp. 93, 107-111, 113, 115, 117-118, 120, 124. E. Orton: Vol. iii, p. 932; vol. v, pp. 999, 1003; vol. vii, p. 280.

	Feet.	Feet
6. Lower Kittanning..........................	2	6
7. Clay and shale	27	0
8. [Vanport] limestone		
9. Clarion		
10. Hecla sandstone	50	0
11. Brookville	2	6

or somewhat less than 200 feet for the whole formation. The Upper Freeport, known locally as the Lucas coal, is in small areas on the hilltops and shows 4 to 6 feet of good coking coal, but it has not been developed. The Lower Freeport is insignificant. The Middle Kittanning, known as the Sheridan coal, is double, but not important within this county. The bottom bench of the Hocking Valley field has disappeared, and there remain only the middle and upper, the latter yielding poor coal; so that, although the bed is sometimes 3 feet 6 inches thick, it is seldom worth working. It is 60 to 70 feet above the Vanport limestone and the interval to the Lower Kittanning is 32 to 44 feet. This lower bed, known as the Newcastle, is the important coal bed of the county and underlies a massive sandstone, at times conglomerate. The Clarion, 1 to 2 feet below the Vanport, and the "steadiest" coal seam in the county, is double and yields somewhat more than 3 feet of fairly good coal. The Brookville, 40 to 50 feet below the limestone, underlies the massive Clarion sandstone, known as the Hecla, and varies from 2 to 4 feet, but is not mined, as the coal has much refuse.*

In Gallia county, east from Jackson and south from Meigs, one finds the section reaching to the Lower Kittanning within the western townships, but the Allegheny is wholly buried along the Ohio. In the western townships the Middle Kittanning is about 480 feet below the Pittsburg, and the place of the Brookville, according to a boring, is 129 feet lower, or 609 feet below the Pittsburg. No well records are available for Gallia except along the Jackson border, but Doctor White gives one in Mason county of West Virginia directly opposite Gallipolis, in Gallia. It begins about 200 feet below the place of the Pittsburg coal bed, the figures being approximate only, as that coal bed is wanting at Gallipolis, though it was found by Andrews, very thin, at a few miles back. In this well the first coal bed is at 472 feet and the second at 238 feet lower, or 710 feet below the Pittsburg. The relation between the coal beds is that between the Upper Freeport and the Brookville in western Gallia, and in this well the bottom coal bed rests, as in western Gallia and at so many other places farther north, on a great sandstone. It is evidently

* E. B. Andrews: Vol. i, pp. 154, 159, 160-161.
E. Orton: Vol. v, pp. 1026-1031.

the Brookville, and the increased interval as compared with 10 miles farther west is in accord with what has been found all the way southward, but the actual interval from the Pittsburg is probably barely 700 feet.*

Returning to the western outcrop in Scioto, one finds the whole section on the Lawrence border, where at Panther hill the thickness of the formation is barely 175 feet. At a few miles east, in northern Lawrence county, Mr McMillin's section shows all of the coal beds present except the Clarion and the total thickness is approximately 200 feet. The Upper Freeport, in most of the region unimportant, reaches great development in the Waterloo field of northern Lawrence and the adjacent part of Gallia, where it was first correlated accurately by Mr McMillin. It is a double bed, 5 to 6 feet thick. The Lower Freeport is persistent within a broad strip of western Lawrence, where it is commonly about 4 feet thick and is known as the Hatcher bed. The Middle Kittanning (Sheridan, Coal 6) is a "steady and excellent seam," usually more than 3 feet thick and yielding in many places an open burning coal. It is a double bed, apparently without the lower or bottom bench of the Hocking valley. The Lower Kittanning (Newcastle) is a good coal, 3 feet 6 inches thick in the western part of the county. The Clarion (Limestone coal), underlying the Vanport, enters from the north as an important bed, but decreases quickly southward and eastward and disappears, but the Brookville persists, though becoming thinner southward and worthless throughout.

Sections by Professor Orton, Doctor White, and Mr McMillin have been measured on the Ohio at and above Ironton, on the southern border of Lawrence county, which make the thickness of Allegheny 240 feet, showing a notable increase in 12 miles southward. No sections have been obtained along the easterly side of the county along the Ohio, as the character of the surface prevents exposures; nor are there any well records; but at Central City, in Cabell county of West Virginia, 10 or 12 miles southeast from Ironton and at the same distance from Mr McMillin's measurements in northern Lawrence, a well record shows black slate at 670 feet below the Pittsburg coal bed, with a limestone at 203 feet above it. This is the relation of the Shawnee limestone and Brookville coal farther west. The interval, Pittsburg to Brookville, is 630 at Ironton, about 700 feet at Gallipolis, and in each case, as here, the great sandstone of the Pottsville begins below the coal. The black shale at

* E. Orton: Vol. v, pp. 1028, 1049-1050.
I. C. White: Geology of West Virginia, vol. i, p. 273.
J. A. Bownocker: Bulletin no. 1, p. 279.

Central City represents the Brookville coal bed, which has persisted more thoroughly than any other from Tyler county of West Virginia and Monroe of Ohio.*

KENTUCKY

Passing over into Kentucky, one enters Greenup county opposite Lawrence of Ohio. The Allegheny area is bounded at the west by the Little Sandy river, which flows northward from Elliott county through Carter and Greenup to the Ohio river, reaching that stream at about 10 miles below Ironton. Boyd county, east from Greenup, extends to the Big Sandy river, the state line. Professor Crandall's generalized section for Greenup, Boyd, and Carter counties is:

	Feet
1. Sandstone [Buffalo and Mahoning]	75
2. Coal bed 9 [Upper Freeport]	
3. Sandstone and shale	50
4. Coal bed 8 [Lower Freeport]	
5. Shale and sandstone	40
6. Coal bed 7 [Middle Kittanning]	
7. Shale and sandstone	40
8. Coal bed 6 [Lower Kittanning]	
9. Sandstone or shale	13
10. Ore and limestone [Vanport]	
11. Shale and sandstone	30
12. Coal bed 5 [Brookville]	
13. Interval	37
14. Coal bed 4 [Tionesta]	

Two limestones are important in these counties; the lower, or First Fossiliferous, is between the Freeport coal beds at 10 to 25 feet above the Lower, and is present in all sections where not cut away by the Butler sandstone; it is often termed the "Yellow limestone," as is the Shawnee, its equivalent in Ohio. It seems to be non-fossiliferous in Ohio, but in Kentucky it carries a characteristic Carboniferous fauna. The Second Fossiliferous limestone is in the Conemaugh and is the Lower Cambridge of southern Ohio. These two limestones are persistent and enable one to carry the section where the coal beds are absent or concealed. The Vanport limestone is practically continuous along the western outcrop into Elliott county, beyond which it has been recognized at a few points in Morgan county as well as in northern Breathitt farther south; but in both Morgan and Breathitt the localities are somewhat widely separated and the continuous outcrop ends in Elliott. This limestone seems to be

* E. Orton: Vol. iii, p. 928; vol. v, pp. 1038, 1046, 1054.
E. McMillin: Vol. v, p. 122, and personal communication.
I. C. White: Bulletin no. 65, p. 135.

non-fossiliferous throughout Kentucky. It is accompanied, as in Ohio, by an important iron ore; this at one locality in Elliott county is so loaded with quartz pebbles as to be worthless. Eastwardly the Vanport limestone disappears along the Ohio river at about 4 miles below Catlettsburg, and its eastern limit appears to be a line extending almost due south from Ashland on the Ohio for about 30 miles into southern Lawrence, beyond which information is lacking. The ore persists eastwardly for a short distance beyond the limestone, but it too disappears before the state line has been reached.

The Clarion coal bed is wanting along the Ohio river; the Brookville is missing in a section below Hanging Rock, but is present near Ironton and persists thence to where it passes under the river. It is not reported at Catlettsburg on the state line. The Clarion (Hecla) sandstone overlies the Brookville and in one section fills the whole interval to the Vanport limestone. The Lower and Middle Kittanning, Lower and Upper Freeport coal beds are apparently persistent along the Ohio border, but the only one holding its thickness is the Lower Kittanning. The Middle Kittanning, 7 feet thick at Ironton, becomes a mere trace at Catlettsburg, while the Freeport beds are thin everywhere. A massive sandstone overlies the Lower Kittanning and near the West Virginia border another underlies it, no doubt continuous with the Clarion, as the Vanport limestone has disappeared.

Along the western outcrop in Greenup, Carter, Elliott, Morgan, and northern Breathitt the exposed section rarely extends much above the Vanport horizon, though occasionally it includes the whole formation. In Greenup and Carter the Clarion coal bed appears occasionally directly under the Vanport limestone and resting on the Clarion sandstone; but the bed is so irregular throughout that it is not included in the numbered scale. The Brookville is present in those counties wherever its horizon is exposed, but in Elliott no trace of it has been discovered, and there is no certainty that it exists in Morgan; there seems, however, to be no doubt respecting its presence in northern Breathitt, where Mr Hodge's sections showing the Vanport limestone are sufficiently clear. In that county it is from 20 to 50 feet below the limestone, the interval varying as in Carter county. At one place it seems to be triple, the benches in a vertical space of 20 feet, and the interval to the Vanport is filled with sandstone, the Clarion. The Brookville, usually either cannel or splint, rarely attains economic importance.

The Kittannings seem to be traceable into Elliott and the Middle is occasionally workable. The Lower Freeport, usually thin, apparently

disappears before reaching Elliott county. The Upper Freeport is seen rarely. In Elliott county the rocks of the Allegheny become coarse, this condition becoming more marked southwardly, so that beyond that county the section above the Vanport horizon can be followed only with extreme difficulty. The Lower and Middle Kittannings should be reached in northeast Breathitt, where the section extends at one locality to 450 feet above the Tionesta coal bed, or to about 350 feet above the place of the Vanport limestone.*

In Boyd and Lawrence counties, east from the narrow outcrop, the Brookville seems to be persistent. Ordinarily it is thin, but in central Lawrence, near Louisa, it is a mass 10 feet 8 inches thick with this structure:

	Feet.	Inches
Coal	0	8
Shale	1	8
Coal and sandstone	0	7
Shaly coal	3	0
Impure coal	2	3
Coal	2	6

The Kittannings and the Lower Freeport are generally present, but the Upper Freeport is absent in considerable areas. The Butler sandstone is often continuous with the Mahoning above and at times extends downward, so as to cut out the Upper Freeport (First Fossiliferous, Shawnee) limestone. It is quite possible that the absence of the Clarion in so much of Kentucky is due to the upward extension of the Clarion sandstone. In southern Lawrence the coal beds become uncertain and in some of the sections they seem to be wholly wanting. In much of Johnson county, south from Lawrence, the Allegheny has been removed, but it is probable that the whole section is preserved in portions of Martin county, east from Johnson, along the West Virginia line; the tracing, however, is not sufficiently close to make possible the correlation of coal beds.

Still farther south the conditions become very complex; the coal beds divide, the intervals thicken, and the true relations will be determined only by patient tracing in detail. Correlations offered by Professor Crandall and Mr Hodge as the result of rapid reconnaissance must be accepted, in accordance with their suggestion, as merely tentative. The

* A. R. Crandall: Geol. Survey of Kentucky, Greenup, Carter, and Boyd counties, pp. 22, 33, 49, 53, 59, 63; pl. 1, 25; fig. 2, 26; fig. 1, 31; sections 34, 35, 51-52, 56, 58-59, 61-62, 69, 78, 82; Elliott county, pp. 10, 11-13; Morgan, Johnson, and Magoffin, p. 17.
J. M. Hodge: Southeastern Kentucky coal fields, p. 107, sections 56, 81, 84-85, 87.

work by those observers seems to show that Allegheny beds extend southwestwardly to not less than 75 miles beyond Martin county.*

WEST VIRGINIA

Returning now to the east side and entering West Virginia in Monongalia county, west from Chestnut ridge, one may follow thence to the Kanawha river the easterly boundary of the Allegheny and afterward, mostly by means of oil-boring records, trace the section across the state to make connection with Ohio.

Morgantown is about 8 miles south from the Pennsylvania line. The exact section there was obtained by Doctor White's measurements of a core. Other measurements by him between that place and Webster, 25 miles southward, in Taylor county, may be grouped with that at Morgantown:

I. Near Morgantown, 9 miles south from Pennsylvania line.
II. Booth's creek, 6 miles south from Morgantown.
III. White Day, 12 miles west of south from Morgantown.
IV. Valley Falls, 20 miles west of south from Morgantown.
V. Webster, 5 miles southeast from Valley Falls.

	I		II		III	IV		V	
	Ft.	In.	Ft.	In.	Ft.	Ft.	In.	Ft.	In.
1. Pittsburg coal									
2. Interval	561	0	...	..	..	..	..		
3. Upper Freeport coal.....	5	0	6	0	3	7	8	624	0
4. Fireclay	7	0	60	0		55	0		
5. Sandstone [Butler]	53	0							
6. Lower Freeport coal.....	Thin		4	0		3	9	2	0
7. Shales and fireclay	22	0							
8. Sandstone and fireclay ..	7	0	...	..	87	16	0		
9. Black shale, sandstone...	15	0	...	..	..	..	..	53	0
10. Upper Kittanning coal...	2	10	...	..	..	1	0		
11. Shales, fireclay	32	6	120	0	..	37	0		
12. Middle and Lower Kittanning coal	8	0	...	..	15	5	0	4	9
13. Fireclay shale	15	0							
14. [Kittanning] sandstone ..	54	2	...	..	57	45	0	44	0
15. Shale	2	4							
16. [Brookville] coal	1	6	2	3	5	1	2	5	10
17. Fireclay, shale	21	6	...	..	13	25	0	10	0

to the Pottsville sandstone. At Morgantown the Lower Freeport coal is 627 feet below the Pittsburg coal bed and at Webster it is 624 feet. At Morgantown the Upper Freeport is 274 feet below the Ames limestone;

* A. R. Crandall: Greenup, etc., pp. 68-69, pl. 28, figs. 2, 4, 30; fig. 7, 31; fig. 5; Morgan, etc., p. 21.

at Grafton, a few miles northwest from Webster, it is 250, and at Webster it is about 255, assuming the same interval to Lower Freeport as at Valley Falls. At Valley Falls the interval from Lower Freeport to Brookville is only 88 feet, but at Webster it is 102 feet. At the latter locality the sandstone below the Brookville is practically continuous for 220 feet, to the bottom of the boring.

The Allegheny is about 250 feet thick near Morgantown, but the thickness decreases southwardly; on Booth's creek it is 192 plus the interval between Brookville and Pottsville; on White Day it is 179; at Valley Falls, 196 feet 7 inches, and at Webster not more than 175 feet, thus showing a loss of at least 75 feet in less than 25 miles. The writer is responsible for the correlations, the local names for the beds being different in many places from those given. The lowest bed on Booth's creek is known locally as the Lower Kittanning and the lowest at Webster as the Lower Freeport.

It is necessary to give the relations in detail for this area, as it is the critical area for determination of the relations farther south. Within this area one observes the somewhat abrupt change from the Pennsylvania section to that of the eastern outcrop in West Virginia. The section at White Day enables the writer to correct his identification of the Brookville at Webster with the Lower Kittanning in the tentative correlation offered in description of the Pottsville section for the eastern outcrop. This correction makes necessary the transfer of the Roaring Creek sandstone to the Pottsville, but it in no wise affects the conclusions respecting the Pottsville of the Kanawha area.

On Deckers and Booths creeks of Monongalia county a dark shale, the Uffington of I. C. White, intervenes between the Upper Freeport coal and the overlying Mahoning sandstone. It is extremely rich in marine fossils and in many ways closely resembles the dark shale associated with the Brush Creek limestone of the Conemaugh.*

Ascending the Valley river from Webster, one finds at Moatsville, in Barbour county, the great sandstone of the Webster boring forming bold cliffs with, as at Webster, a variable coal bed at 10 feet above it. This bed, 3 feet thick at Moatsville, is 12 feet 6 inches half a mile away, where it has a sandstone parting 8 feet. The bottom of this Brookville coal bed at Moatsville is 149 feet below the top of a 3-foot coal bed, but at the other locality the interval is 147 feet. The upper bed is the Upper Freeport. At 5 miles southeast from Moatsville a record and boring at the Hall well show the Lower Freeport at 607 feet below the

* I. C. White: Geology of West Virginia, vol. ia, p. 151; vol. ii, pp. 230 and 346, 233, 356 and 605, 347, 355.

Pittsburg and 295 below the Ames limestone. The Brookville is at 105 feet lower, or 712 feet below the Pittsburg and 538 feet above the red shale of the Lower Carboniferous. At Philippi, 4 miles farther southeast, a boring shows the Lower Freeport at 106 feet above the Brookville, the latter at 522 feet above the red shale. There the Lower Kittanning is 3 feet thick and 25 feet above the Brookville. Doctor White gives a combined exposure and record just below Philippi, thus:

	Feet.	Inches
1. Sandstone and shale	70	0
2. Upper Freeport coal	3	0
3. Concealed and sandstone	75	0
4. Upper Kittanning coal	4	3
5. Concealed, shale, sandstone	40	0
6. Middle and Lower Kittanning coal	6	0
7. Shale	15	0
8. Clarion [Brookville] coal	2	0
9. Shale	10	0
11. Roaring Creek sandstone [Pottsville]		

making the interval from Upper Freeport to Brookville 140 feet and the whole thickness of the Allegheny 155 feet. The relation of the Brookville to the Pottsville is the same as at Webster and Moatsville, as well as at Newburg, in Preston county, 10 or 12 miles east from Webster. The Freeport sandstone overlying the Upper Kittanning is coarse and much of it is pebbly. A limestone is present at a few feet above the Brookville coal at Webster, Moatsville, Valley Furnace, and at Meriden below Philippi. It was used as a flux at Valley Furnace, where it is 10 feet above the coal; this is suggestive of the Putnam Hill horizon. The Roaring Creek sandstone, about 60 feet thick, is continuous with the lower sandstones in much of the area southward, and, forming bold cliffs, makes easy the tracing of the coal bed. The Brookville (Arden, Roaring Creek) coal bed retains its place at 10 to 15 feet above the sandstone, constantly rising, so that near the southern border of Barbour county it is 200 feet or more above the Valley river. The structure is complex, there being nine layers of coal and shale, in all 14 feet thick, with one bench of coal 3 feet 1 inch.*

From this locality southward the Brookville is high up in the hills and no detailed section of the rocks above it is available until one reaches the Kanawha waters. The bed retains its tendency to divide and is from 6 to 10 feet thick in Randolph south from Barbour. In Webster, south from Randolph, it is from 5 to 7 feet thick and its top bench is

* I. C. White: Geology of West Virginia, vol. *ia*, pp. 346, 348; vol. ii, pp. 297, 312, and 605, 357, 360, 425.

occasionally either splint or impure cannel. Overlying the coal in this county is a succession of massive more or less pebbly sandstone, shown on one knob in three benches, but with the intervals concealed. The thickness is 200 feet. This great sandstone mass, the Charleston sandstone of M. R. Campbell, is a conspicuous feature from Randolph county southward. Passing over into Nicholas county, one finds the blossom of the Brookville near Gilboa under 150 feet of massive pebbly sandstone, all other coal beds appearing to be absent. Two miles west from this locality the Kanawha black flint appears, just over the Brookville coal bed and under the great mass of sandstone. In western Nicholas, the Flint is 8 feet thick and 10 feet above the Brookville, which is triple, two of the benches being splint. From this locality, Doctor White has followed the Brookville eastward and southward; it breaks into many benches and the shale partings show great variations in thickness. At Powell mountain in this county the section is:

	Feet.	Inches
1. Massive pebbly sandstone	180	0
2. [Upper Freeport] coal	5	0
3. Concealed	5	0
4. Massive sandstone	85	0
5. [Kittanning] coal	Blossom	
6. Sandstone, shale	50	0
7. [Brookville] coal, including shale 10 feet	15	3

At this Nicholas locality one is on the waters of Gauley river, along which the Brookville coal bed is seen in all the hills to the Kanawha river, in Fayette county, where one has this section at the mouth of Armstrong creek:

	Feet.	Inches
1. Massive sandstone	80	0
2. Shale	10	0
3. Number 5, block [Kittanning] coal	5	4
4. Concealed	5	0
5. Massive sandstone	65	0
6. Concealed	5	0
7. Kanawha black flint	10	0
8. Shales, concealed	12	0
9. [Brookville] coal	3	6

Number 9 is the Stockton coal bed of the Kanawha region. The exact relations of the "Number 5" coal bed can not be determined. The interval between it and the Stockton shows great variation along the Kanawha, but the bed is characteristic throughout, its coal differing from that of any other bed in the section. It is apparently the intermediate bed occasionally seen farther north and doubtless represents a Kittanning

horizon. The Flint holds the place of the limestone seen in Barbour county.*

Returning now to Barbour county at the north, another line may be followed to the Kanawha river at Charleston.

At many places along the Valley river as well as in the Roaring Creek region, one finds at 10 to 25 feet below the main Brookville another bench resembling the main coal in structure, but usually of inferior quality.

The Brookville (Arden, Roaring Creek) coal bed is mined at many localities in Barbour, Upshur, and Randolph counties, in what is known as the Roaring Creek field, where it usually yields, after removal of partings, about 7 feet of coal. In its tendency to break up into many benches it resembles the Upper Freeport of southern Pennsylvania even more than it does the Brookville in that area, and this resemblance, added to the presence of the great overlying sandstone, led Stevenson into the mischievous error of correlating this bed with the Upper Freeport. The variations in thickness and quality are extreme, there being at one locality, according to Stevenson, 22 feet of shale and coal, wholly worthless, while at a short distance away the bed is double and only 4 feet 6 inches thick. Doctor White's sections show it in this area 10 feet or less above the Roaring Creek (Pottsville) sandstone and underlying a massive pebbly sandstone often unbroken for 60 feet.

The Buckhannon enters Valley river at about 5 miles south from Philippi. In ascending this stream one goes southwest for somewhat more than 5 miles and the Brookville coal bed remains above water level; but at the Barbour-Upshur line the direction is changed to west and the coal goes under quickly, so that at Buckhannon, 12 or 13 miles southwest from Philippi, it is thought by Doctor White to be not less than 300 feet under the stream's bed. Southward from that place it rises rapidly, and at Cutrights, where it is thought to be about 80 feet under the river, the exposed section is:

	Feet
1. Silicious limestone	5
2. Concealed, red shale	70
3. Massive sandstone	30
4. Coal	Blossom
5. Marly shale, concealed	35
6. Massive sandstone	25
7. Concealed	50
8. Coal	3
9. Fireclay and shale	6
10. Massive sandstone	30
11. Concealed to stream	25

* I. C. White: Geology of West Virginia, vol. ii, pp. 363-366, 368-369, 370-371, 459.

A thin coal bed is reported here just below the section in the river bed. The coal bed, number 8, is between 140 and 150 feet above the Brookville; it comes down to the railroad grade within a short distance, where it underlies a black shale filled with marine fossils. As the coal bed is in the place of the Upper Freeport, this is evidently the Uffington shale of the Morgantown region. At Sago, 7 miles south from Buckhannon, the Brookville comes up, 4 feet 6 inches thick and 10 feet above the massive Roaring Creek sandstone; but at 3 miles farther south the bed is double, the upper part, more than 3 feet thick, being largely cannel shale, while the lower portion, 11 feet 11 inches thick, is in 8 layers of coal and shale and still only 10 feet above the sandstone. Here the Upper Freeport is 150 feet above the Brookville, 4 feet 2 inches thick and in 5 benches of coal and slaty coal. It overlies a massive sandstone, but the interval to the Brookville is mostly concealed. At Alexander, 15 miles south from Buckhannon, the Brookville is far up in the hills, 13 feet thick and 10 feet above the Roaring Creek sandstone, with another massive pebbly sandstone, 60 feet thick, beginning at 5 feet above it. The most remarkable feature in this whole region is the uniformity of the interval between the Brookville and Roaring Creek sandstone, which varies little from 10 feet in an area of more than a thousand square miles.

On the east side of Lewis county, about 6 miles west from Buckhannon, a well record is given by Doctor White on the authority of Mr F. H. Oliphant. This shows the great sandstone overlying the Brookville 80 feet thick, but divided midway by 20 feet of shale, a breaking up in the westerly direction, which, as will be seen, becomes so marked that this, like the other sandstones of the whole section, can be traced with little certainty. The coal bed, 12 feet thick, is said to be 775 feet below the Pittsburg, and no higher coal is noted in the record. Near Ireland, in southern Lewis, and about 12 miles west from Alexander, in southern Upshur, a section and boring combined show coal 3 feet 5 inches at 612, a thin coal at 697, and a third, not measured, at 721 feet below the Pittsburg. The highest bed is evidently the Lower Freeport, and the interval would place the lowest at the Brookville horizon, though the distance to the Pittsburg is about 50 feet less than that assigned farther north. At a few miles south the Brookville is exposed, 13 feet thick, with a sandy parting which occasionally becomes 8 feet of sandstone. The coal above is soft, but that below the parting is splinty. Many well records exist for Lewis county, but for the most part they are incomplete, noting only the sandstones.

Passing over into Braxton county, west from Webster and southwest from Lewis, one finds at 5 miles east from Sutton the Upper Freeport (Mason) coal 150 feet above the Brookville, 22 to 24 inches thick and underlying 3 feet of dark plant-bearing shales on which rests a 3-inch coal bed. It is 160 feet below the first red bed. This interval of 140 to 150 feet between Upper Freeport and Brookville prevails in most of this area of Upshur, Lewis, Webster, and Braxton counties, though occasionally it is a little less, as Doctor White's section in western Webster, near the Braxton line, shows:

	Feet
1. Concealed and deep red shale	40
2. Concealed, massive sandstone	140
3. [Upper Freeport] coal bed	2
4. Concealed, massive sandstone, pebbly	130
5. Dark shale	5
6. [Brookville] coal bed	10
7. Concealed, massive sandstone	160

Here the Brookville shows the sandstone parting 3 feet thick, and the coal of both divisions is poor. The great sandstone mass, Charleston of Campbell, is well marked thus far west. The Brookville passes under Elk river 2½ miles from Sutton, and, just before passing under, it apparently breaks up as it does farther north, the section being

	Feet.	Inches
Coal	0	0 to 10-12
Interval	30	0
Coal	3 to 2	6

and the lower division is splinty. The bed shows much variation in a little area of a few square miles, but remains comparatively thin, seldom exceeding 5 feet. At a mile and a half below Sutton the coal is 160 feet below the surface, 6 feet thick, underlying the massive white sandstone 80 feet thick and resting on the Pottsville sandstone, which is continuous for 280 feet. The Upper Freeport is below the surface here. At 5 or 6 miles below Sutton, near Frametown, in southern Braxton, a coal 2 feet 6 inches is present at 550 or possibly 600 feet below the Pittsburg, 140 feet below the lowest red bed of the Conemaugh and just above a massive sandstone; it is evidently the Upper Freeport. At many places in Braxton and Lewis the Upper Freeport is overlain by dark shale carrying great numbers of plant impressions.

Thus far the tracing of the section has been comparatively simple. The thickness of the Allegheny decreased from 250 feet near the Pennsylvania line to barely 175 feet in southern Taylor county; thence to

southern Braxton it has varied from 150 to 165. In much of the area the Upper Freeport has been accompanied by its plant-bearing shales and in most of the area the interval to the Brookville coal bed has been occupied by sandstone; whether or not an intermediate coal bed is persistent is uncertain; it is wanting in the well records.

For a distance of about 16 miles from Frametown no sections are available, but at Clay Courthouse, in Clay county, southwest from Braxton and northwest from Nicholas, is a section by Doctor White, thus:

	Feet
1. Concealed with much red shale	90
2. Coarse pebbly sandstone	60
3. Concealed, shales, some red	100
4. Massive sandstone, large quartz pebbles	60
5. Concealed and sandy shales	130
6. Coal bed	2 to 3
7. Fireclay, shale	10
8. Sandstone, massive, pebbly	90
9. Concealed and sandstone	160
10. Black shale and thin coal	3
11. Massive sandstone and concealed	100

As Number 10 is just below the Black Flint, it is at the Brookville-Stockton horizon. The interval between this bed and Number 6 is too great, the measurements having been made without regard to the dip, and the thickness is probably nearer to 230 feet. This is 90 feet more than the interval between the Brookville and Upper Freeport at 12 miles eastward in northern Nicholas. Associated with the upper bed are plant-bearing shales, from which were obtained the specimens discussed by Mr David White, who referred them to the Freeport horizon. The Brookville is much degraded at Clay, being merely black shale with streaks of coal.

Five miles below Clay, near Yankee Dam, the upper coal bed is 3 feet 4 inches thick and 310 feet above the Coalburg coal bed, somewhat less than at Clay, where the interval is about 330 feet. This, if the interval between the lower coals remain the same, would place the upper bed at about 210 feet above the Brookville-Stockton. The Upper Freeport here is 150 feet below the top of a great pebbly sandstone on which rest reddish shales succeeded by deep red beds.

According to Doctor White, this bed is traceable in the river hills from the Yankee Dam locality to and beyond Queens shoals; at that place, 10 miles west from Clay, the coal is 175 feet above the Black Flint, with 200 feet of mostly massive pebbly sandstone intervening between it and the first red beds of the Conemaugh, which are 410 feet

above the flint. The Stockton coal bed appears 2 miles farther up the river at 7 feet below the flint which is in the river bed at the shoals. At Clendenin, 5 miles below the shoals, the upper bed is mined at the water's edge, and it soon goes under, to come up again at 5 or 6 miles from Charleston, where it is mined at the Graham mines near Mason. On Two-mile creek, near Charleston, Doctor White's section is:

	Feet
1. Sandstone and concealed	85
2. Sandstone, massive, pebbly	75
3. Mason coal bed	2
4. Shales	10
5. Sandstone, coal near middle	120
6. Shales	10
7. Black flint	5
8. Shale	2
9. Stockton coal bed	

The Mason coal bed is that mined at Mason, Clendenin, and Queens shoals, the interval to the Flint having decreased 35 feet from the last place. At all of these localities it underlies a bed of shale rich in fossil plants which have been studied by Mr David White. Comparison of the flora from this bed with that obtained at Clay leads him to regard the beds as at different horizons, the bed at Clay being Freeport and that at Queens shoals nearer to the Kittanning. Mr M. R. Campbell comes to the same conclusion on stratigraphical grounds. Detailed sections between Clay and Queens shoals are unpublished; lacking those, one may make use only of such material as is available. The interval from Upper Freeport to Brookville evidently decreases westward from Clay, losing 20 feet in 5 miles; at Queens shoals, 5 miles farther, the interval between the upper coal and the Brookville is about 187 feet, 23 feet less than below Yankee Dam, while at Charleston, somewhat more than 20 miles southwest from Queens shoals, the interval is but 147 feet. As will be seen in succeeding paragraphs, the interval between this Mason coal bed and the Brookville shows much variation along the Kanawha southeast from Charleston.*

Ascending the Kanawha river from Charleston, one finds the interval between the Mason and Brookville-Stockton increasing from 135 feet at Porters run to 198 feet at Witchers run, 14 miles southeast. The intermediate coal, noted in the Two-mile section and known as the "Number 5, block," is very thin and only its blossom has been seen thus far, but at North Coalburg, 2 miles farther up the river, it is 3 feet 10 inches thick,

* David White: Bull. Geol. Soc. Am., vol. 11, pp. 171-173.
M. R. Campbell: Jour. of Geol., vol. xi, pp. 462, 465, 467.

90 feet below the Mason and 65 feet above the flint. The Stockton is concealed here, but at Coalburg the coals are all shown and the interval from Mason to Stockton is 186 feet. The "Block" is mined at a number of places farther up the river at 41 to 75 feet above the flint, but no higher bed is exposed until near the Fayette County line, where, at lock number 3, a bed supposed to be the Mason is at 206 feet above the flint, 40 feet more than at Coalburg and 76 feet more than at Porters run, near Charleston. Whether this be the Mason or not can not be determined, intermediate measurements being wanting.

At Coalburg the Mason is accompanied by its plant bed. The coal is insignificant near the eastern outcrop, but it becomes 17 feet thick, partings included, near Coalburg, whence northwestward it decreases so as to become insignificant as it approaches Charleston, though, as already seen, it becomes economically important along Elk river, northeast from that city. The "Block" is a valuable bed on the upper Kanawha, yielding an excellent open-burning coal coming out in blocks. The thickness of this part of the bed near the Fayette border is from 5 to 6 feet; down the river, however, the thickness decreases, and at Coalburg it is 2 to 3 feet, but retaining its "blocky" feature; thence it quickly diminishes, and near Charleston it is only a few inches and is often wanting, cut out by the sandstone. A thin coal bed occurs at some places just above the flint, but it appears to be absent at Charleston. The flint varies from 5 to 10 feet; changes from tough typical flint to silicious shale and usually is fossiliferous, as is also the shale associated wtih it. The interval to the Stockton-Brookville coal bed is from nothing to 18 feet. This bed is so irregular that it is of uncertain value economically. One of its partings thickens at times so as to separate the divisions into two distinct beds, and the parts are known as the Stockton and Lewiston. At times one or the other of the divisions is wanting. The coal varies from splint to cannel, but usually one finds some layers of soft coal.

The Charleston sandstone of Mr Campbell includes the great mass of sandstones succeeding the flint along the Kanawha and its tributaries. It is the "series of coarse sandy or conglomeratic beds which separates the Kanawha formation from the red and green shales and green sandstones of the formation next above." The Kanawha formation has the flint as its upper boundary; the formation above the Charleston sandstone is termed Braxton by Mr Campbell. The sandstone, made up of beds of coarse material separated by shales and coal beds, is about 300 feet thick at Charleston, but farther south on Coal river, in Boone county, it is about 400. At a little way northwest from Charleston it is

at least 405 feet, but near Winfield, in Putnam county, it is apparently only 175 feet.*

This great mass of sandstone, coarse and in many portions pebbly and marking the eastern border of the field, includes not merely the Allegheny but also the lower part of the Conemaugh. It is in a narrow strip, with a width of not far from 25 miles in a northwesterly direction. It is not characteristic of the Pennsylvania and Maryland area east from the Alleghanies; it is not found in the southward continuation of the First Pennsylvania bituminous basin until one reaches Randolph county, though suggestions of it occur farther north; thence to the Kanawha the sandstone appears in increasing quantity and coarseness, so that the several sandstones which have been recognized and named in the northern portion of the field become practically continuous. The great mass and coarseness of these beds in Webster, Braxton, Nicholas, Clay, and Kanawha counties of West Virginia suggest that the shoreline at the east suddenly extended westward near the latitude of southern Barbour county. Southwestwardly from the Kanawha this mass of sandstone can be traced to the Kentucky line across Boone, Logan, Wyoming, and Mingo counties. Northwestwardly from the narrow strip referred to, the mass breaks up quickly, shales increase, and the several divisions, as is ordinarily the case with sandstones, become traceable with little certainty; but locally one finds most unexpectedly conditions which are recalled by Mr Campbell's description of the Charleston sandstone.

It is necessary now to return to the Pennsylvania line, that the section may be traced southward under the western counties of the state to the line of the Chesapeake and Ohio railroad—a task of no little difficulty, as the key rocks disappear, and the coal beds which were formed only around the borders of the field soon thin out. The sole dependence in most of this area must be upon the records of borings which have been published in the Geology of West Virginia.

Beginning with the measurements at Morgantown, one has the following approximate intervals from the Pittsburg coal bed:

	Feet
Upper Freeport coal bed	560
Lower Freeport coal bed	625
Upper Kittanning coal bed	670
Lower Kittanning coal bed	705
Kittanning sandstone, top	730
Kittanning sandstone, bottom	785
Brookville coal bed	785
Pottsville sandstone	805

* M. R. Campbell: U. S. Geol. Survey folios, Charleston, p. 5.

As the sandstones of the Pottsville are as variable as those of any other formation, the bottom of the Allegheny, for comparison, must be taken as the Brookville coal bed.

Ten miles northwest from Morgantown a record shows the Upper Freeport, Upper Kittanning, and the bottom of the Kittanning sandstone as at Morgantown, and the sandstone in the Pottsville is at 820, though in a neighboring well it is at 792, having thickened at the expense of the overlying shale. Ten miles southwest, near Fairview, in Marion county, the Upper Freeport is ill defined in a mass of coal and shale beginning at 556; no other coal is reported. Another record here shows a great sandstone beginning at 565 and continuing to 761 with only two breaks of shale, 28 and 17 feet respectively. No coal whatever is noted in this record except a thin bed at 805 feet below the Pittsburg and 11 feet above the first sandstone in the Pottsville. Eight miles southwest from Fairview, at Mannington, the Hamilton well shows sandy rocks prevailing in the Allegheny and has apparently the same coal horizon at 824, which is too low for the Brookville, unless there be a local thickening of the section. The sandstones vary greatly. Within 3 or 4 miles of Mannington, southwest and west, a sandstone, 115 to 177 feet thick, begins at 647 to 682 and ends at 791 to 804; but in one well it begins at 603 and ends at 913, while in another no sandstone appears between 491 and 728, whence it is continuous to 858. Farther west the mass is less, beginning at 685 to 696 and ending at 742 to 765, but a lower sandstone begins at 785. Three or four miles northwest from Mannington the variations are more notable, wells on a single farm showing the upper sandstone 30 to 170 feet thick and beginning at 623 to 650, while the lower sandstone is found in only one well extending from 742 to 867. Farther west and northwest sandstone predominates in the Allegheny, and the bottom of the formation is not far from 760 feet below the Pittsburg, including in this the shales and clays underlying the place of the Brookville. The Mahoning interval is indefinite and no trace of the Freeport coals exists, so that the boundary between Allegheny and Conemaugh can be fixed only approximately. The latter formation is not far from 540 feet thick. The only coal appearing in any of the records is one at 672 in a well near Joetown, in western Marion—very near the place of the Lower Kittanning. This horizon is occupied by sandstone in most of the records.

Wetzel county is west from Monongalia and Marion. As one passes into this county he enters the area in which the section of Allegheny and Conemaugh shortens.

Near Brink, on the Marion line, the Butler sandstone is present at 565, and another begins at 720, which passes down into the Pottsville. Five or six miles northward, in the northeast corner of the county, the section varies abundantly; in one well sandstone begins in the Conemaugh at 446 and is continuous to 911 feet below the Pittsburg—a condition very similar to that in many wells within the adjoining county of Marshall, at the north, as well as in some portions of Greene county, Pennsylvania, and along the southeast outcrop toward the Kanawha; but in a well near the last this sandstone is broken by shale at 546 and 763, while in three others there is no sandstone whatever in the Allegheny. The extreme bottom of the Allegheny here can not be more than 770 feet; but the interval is less westward, for at Silver hill, 10 miles away, on the Marshall line, the Lower Freeport coal bed is only 575 feet below the Pittsburg, and the first sandstone in the Pottsville begins at 762. Westward the section shortens and the interval from Pittsburg to the first sandstone of the Pottsville decreases from 752 to 714 feet, the last near the Ohio river. In the central part of the county the sandstones are so variable that correlation is impossible and in many of the records the Allegheny and Pottsville are practically all shale. No coal is reported in any of the records, which are very numerous.*

Tyler county is south from Wetzel, along the Ohio river. A detailed record is given at Wick, a few miles east from the Ohio river, which shows a great sandstone beginning at 539 feet below the Pittsburg and continuing for 135 feet; it is separated from the Pottsville sandstone by 30 feet of shale, holding at its base a trace of the Brookville coal bed resting on the Pottsville sandstone at 704 feet. This shale and its coal have been replaced in many places, for midway in the county and southwestward sandstone prevails. At Middlebourne there is sandstone from 537 to 957; in other localities it begins at 490, 514, 550, 595, 600, 602, and is from 200 to 400 feet thick, always replacing the Brookville horizon except at Sistersville, where it ends at 685, but no record of the underlying rock is given. On the southeast, or Doddridge County side, the sandstones are ordinarily less conspicuous, though one record shows a bed extending from 581 to 896 feet below the Pittsburg. No trace of coal, aside from that of the Brookville, appears in any of the records.

Pleasants county, north from Ritchie, is west from Tyler, and, like that county, adjoins Washington county of Ohio.

No coal is noted in any of the numerous records available for this

* I. C. White: Geology of West Virginia, Monongalia, vol. i, pp. 239-240; vol. *ia*, pp. 156-157; Marion, vol. i, pp. 241-242, 245, 346, 348; vol. *ia*, pp. 161-162, 164, 174-175; Wetzel, vol. i, pp. 343-345; vol. *ia*, pp. 177-189, 200-203, 212-213.

county, but in Ohio, on Cowrun, a few miles west, the Brookville coal bed is present at 701 feet below the Pittsburg. The sandstones are unimportant on the westerly side, but a detailed record in the central part of the county shows a sandstone 70 feet thick beginning at 515 and another at 645 extending to 735 and cutting out the Brookville horizon.*

Returning to the east, one may follow the section across Harrison, Doddridge, Ritchie, and Wood counties to the Ohio river.

Near Flemington, in Taylor county, 5 miles west from Webster, in the same county, the Lower Freeport is at 590 feet below the Pittsburg, and the Brookville is at 750 feet, with probably the Lower Kittanning at 711. The combined Mahoning-Butler sandstones are 113 feet, cutting out the Upper Freeport. The only other sandstones are 31 and 21 feet thick, the latter at the Clarion horizon above the Brookville; but at Clarksburg, in Harrison county, 10 miles farther west, the succession as shown by a boring is:

	Feet
1. Pittsburg coal bed	
2. Interval	421
3. Mahoning sandstone	84
4. Shale	35
5. Upper Freeport coal bed	3
6. Slate	27
7. Sandstone	145
8. Slate	20
9. [Brookville] coal bed	2
10. Slate	36
11. Sandstone	87

Here the interval from Upper Freeport to the Brookville is 192 feet and the lower bed is at 737 feet below the Pittsburg. The sandstone, Number 11, is in the Pottsville. The notable change is in the appearance of the sandstone Number 7, which is almost wanting at the east in the sections near Flemington and at Webster. Ten miles west of south from Clarksburg no sandstone appears until 750 feet below the Pittsburg, where the Pottsville begins. The only coal bed recorded is at 600, which can hardly be correlated. In the northwest corner of the county, 9 or 10 miles southwest from Mannington, no coal is reported; a sandstone 110 feet thick begins at 492 feet below the Pittsburg, cutting out the Freeport coal horizons, and another begins at 702, which continues into the Pottsville. At Browns mills, 4 miles southwest and 8 miles northwest from Clarksburg, the upper sandstone is present, ending at 592, but below it are only "slate and shells" for 300 feet. Cherry Camp is 7 miles

* I. C. White: Geology of West Virginia; Tyler, vol. *ia*, pp. 242, 248, 253, 256, 266; vol. ii, p. 391; Pleasants, vol. *ia*, pp. 269, 270-271, 273-274.

south from Browns mills and 10 miles west from Clarksburg. The only sandstone recorded there is 80 feet thick and begins at 642 feet below the Pittsburg. It is clearly the lower part of the sandstone at Clarksburg, which ends at 715 feet. The first sandstone in the Pottsville is at 822 feet below the Pittsburg.

Doddridge county, west from Harrison, is southeast from Tyler. In the northeast corner, near Center Point, 10 miles west from Browns mills, in Harrison, and 10 miles south from Smithfield, in Wetzel, a detailed record shows no trace of coal, but a sandstone 150 feet thick begins at 615 feet and ends at 765, so passing beyond the Brookville horizon. No trace of coal is noted in any record within northern Doddridge; even black shale seems to be wholly absent. Sandstone is unimportant for the most part near the Harrison border and equally so on the Tyler border. The records are dreary lists of slate and "limestone."

Long Run is 10 miles south from Center Point and 8 miles west from Cherry Camp. A coal bed is here at 652 feet below the Pittsburg, a Kittanning horizon, and a sandstone 45 feet thick begins at 688; it is separated by 10 feet of shale from another sandstone beginning at 743 feet. The intervening shale is at the Brookville horizon. A higher sandstone, 544 to 589, represents the Butler interval. In southern Doddridge the sands vary greatly, but that above the place of the Brookville is usually represented to some extent. Coals are absent from both Allegheny and Conemaugh in this portion of the county, but it is possible that a 4-foot coal bed at 15 feet above the "Salt sand," in the southwest corner, may be the Brookville.*

Ritchie county, west from Doddridge, is south from Tyler and Pleasants.

The Pittsburg coal bed is of uncertain occurrence in most of this county, being recognized only in the eastern portion, where, however, it is wanting in many places. Its horizon can be fixed very closely by means of the Logan ("Big Injun") sandstone below and the Washington coal bed above in the Dunkard formation.

At Tollgate, on the eastern edge of the county, a sandstone at the Butler horizon is from 480 to 545 feet below the Pittsburg, the Mahoning sandstone ending at 470 feet. Shales only are below into the Pottsville and no trace of coal is recorded. One mile west a sandstone is reported as beginning at 691 feet and continuing into the Pottsville. At 10 miles west, in the Whiskey Run district, several detailed records are available, one of which shows the Pittsburg coal bed. The Mahoning

* Geology of West Virginia: Harrison, vol. i, pp. 248, 251; vol. *ia*, pp. 317-318, 328-329, 335.

interval is filled with red shale which extends downward into the Allegheny, ending at 565 feet. No sandstone is here, but a coal bed is reported at 755 feet below the Pittsburg, which seems to be too low for the Brookville, as that coal is at 737 feet in Harrison county far toward the east. Near Harrisonville, about 9 miles south from the Whiskey Run wells, a sandstone 105 to 95 feet thick begins at 585 feet below the assumed place of the Pittsburg, and in a well north from the village a great mass of red rock ends at 470, reaching possibly into the Allegheny.

In the eastern part of the county, south from the Baltimore and Ohio railroad, the sandstones are more distinct, the bottom of the Mahoning being at 461 to 501 feet below the Pittsburg. The first sandstone of the Allegheny begins at 572 to 597 and ends at 603 to 673 feet, while a lower sandstone begins at 719 and is continuous into the Pottsville, if, indeed, it be not wholly in the Pottsville; but a well shows only sandstone from 596 to 946 and another from 600 to 1,090 feet, showing the condition already observed locally in other counties. No Allegheny coals are reported in any of the wells within the eastern part of the county. In the western part of the county the sandstones are less important, most of the records showing only shales below the Mahoning to many feet down in the Pottsville; but on the Wood County border a sandstone appears in the lower part of the section, extending from 645 to 720 feet below the Pittsburg. Near Cairo red shale is present in the upper part of the Allegheny, one well showing a bed of 15 feet at 513 and another showing 13 feet at 524 feet below the Pittsburg. On the western border the top of the Pottsville is approximately 735 feet below the Pittsburg, and there is no evidence of coal in the Allegheny formation.

Wood county, west from Ritchie, Wirt, and Pleasants, adjoins Washington and Meigs counties of Ohio. The Pittsburg coal bed can not be recognized with certainty and the varying thickness of the Pottsville and Lower Carboniferous render the "Big Lime" a not altogether satisfactory guide. It is best to begin at the north, where the section is clear in its connection with Ohio.

At Marietta, in Washington county, Ohio, the Brookville is 830 feet above the Berea grit; at Parkersburg, in Wood county, West Virginia, it is 843—a very close agreement in view of the fact that the measurements were made by cable and not by steel tape. No other trace of coal appears at Parkersburg. At this place the Brookville is 275 feet below the top of a sandstone, whose upper portion is in the Mahoning interval, this top being 1,125 feet above the Berea. At the Hendershot well, in northern Wood, about 11 miles south from Marietta and 5 or 6 miles east from Parkersburg, the top of this sandstone is 1,111 feet above the Berea. The

top of the "Salt sand" at Marietta is 805 feet above the Berea, but at Hendershot the sandstone extends upward to 916 feet, cutting out the Brookville horizon. Southward the "Big Lime" appears and the Logan thickens, so that the intervals to the Berea are increased nearly 200 feet. The Mahoning sandstone ends at 465 feet below the place of the Pittsburg coal bed and only shales are present below to 841 feet, where the first great sandstone of the Pottsville is reached. No trace of the Brookville or other coal is here, but three red beds, 25, 40, and 25 feet respectively, are in the Allegheny, the bottom of the lowest being 650 feet below the assumed place of the Pittsburg. It is possible that the place of that coal bed has been placed too high, and that it may belong 50 feet lower, within a great mass of red shale, in which case the first of the red beds would be in the Conemaugh. At a little distance west a deep well shows sandstone 110 feet beginning at 553, and the "Salt sand" begins at 1,020, with an intermediate sand at 713 feet; this is at the top of the Pottsville, and the higher sandstone is one which in part or in whole is followed readily in much of Ohio as occupying the middle of the Allegheny.*

Returning to the east, the section may be traced across the remaining counties to the Kanawha river and the Chesapeake and Ohio railroad.

At Vadis, on the Lewis-Gilmer line, a detailed section shows the Mahoning sandstone ending at 490 feet below the Pittsburg and only shales thence to 715 feet, where begins a sandstone 83 feet thick and evidently in the Pottsville. The condition is as in Harrison county, 15 miles northwest. Five miles southwest, near Troy, in Gilmer county, the same condition appears, except that the sandstone in the Pottsville begins at 748 feet. At Glenville, 10 miles southwest from Vadis, the Mahoning ends at 534 and sandstone 80 feet thick begins at 660 feet, reaching into the Pottsville. Near Stouts mills, 8 miles southeast from Glenville, on the Braxton border, the succession is practically all sandstone from 549 to 949 feet below the Pittsburg, there being only two interruptions, one of 25 feet at 614 and one of 3 feet at 774, the last being a coal bed which is too low for the Brookville; but at 2 miles northward shale is present for 110 feet above the sandstone at 777 feet, while above the shale is a continuous sandstone into the Conemaugh. Three or four miles east in Braxton county there are only two thin sandstones in the Allegheny, and a coal bed in the upper part is very near the Lower Freeport horizon. At Stumptown, 12 miles southwest from Stouts mills, the lower half of the Allegheny is sandstone, extending to 715 feet below the Pitts-

* Geology of West Virginia: Ritchie, vol. i, p. 318; vol. ia, pp. 410, 412-413, 415, 417-419, 420-422, 425-426, 431, 433-435, 439-440; Wood, vol. i, pp. 285, 287, 294-297.

burg, very near the place of the Brookville coal bed. In southern Gilmer a record at Rosedale shows almost no sandstone. At Tanner, 8 miles west from Glenville, the sandstone seen at the latter place is only 68 feet thick and is divided midway by 23 feet of shale.

Calhoun county is west from Gilmer. The records here are somewhat indefinite, as the Pittsburg is wanting. Two records in the northern part of the county show a sandstone, 40 feet in one, 28 feet in the other, which belongs to the interval of that seen at Glenville 660 feet below the Pittsburg. A lower sandstone beginning at 674 feet is in the Pottsville.*

Wirt county, southwest from Ritchie and northwest from Calhoun, is east from Wood.

The Cowrun anticline of Washington county, Ohio, passes across the eastern side of Wirt and brings up the Ames limestone, which is exposed frequently near Burning Springs. The Pittsburg coal bed is rarely present either in exposed sections or in well records, but a record on the east side and another on the west side show that bed and afford means of comparison. Two records in detail near Burning Springs are referable to the Ames limestone, which in the Cowrun area of Ohio is about 240 feet below the Pittsburg coal bed and 150 feet above the Upper Freeport, but the lower interval increases eastwardly.

In the wells within the Burning Springs area a sandstone persists 44 to 71 feet thick and beginning at 682 to 687 feet above the "Big Lime." At the Ritchie line, 5 miles east, a sandstone 60 feet thick begins at 725 feet above that limestone and is 553 feet below the Pittsburg. The sandstone at Burning Springs is 269 feet below the Ames limestone, so that limestone, if the relations to the "Big Lime" be the same as at the Ritchie border, would be 311 feet below the Pittsburg, which is highly improbable. It is better to regard the lower portion of the section as thinning westward and to accept 725 at the Ritchie border as equivalent to 686 at Burning Springs. On this basis one may place the coals recorded in one of the wells thus:

1.	188 feet below the Ames....	472 feet below the Pittsburg
2.	290 " " " "	574 " " " "
3.	358 " " " "	642 " " " "
4.	409 " " " "	693 " " " "
5.	510 " " " "	794 " " " "
6.	546 " " " "	830 " " " "

The error is very slight; numbers 1 and 4 are very near to where one should expect the Upper Freeport and the Brookville. In Wood county

* Geology of West Virginia: Gilmer, vol. i, pp. 257-258, 260; vol. ia, pp. 378, 380, 383-384, 386; Calhoun, vol. ia, p. 396; vol. ii, p. 395.

the interval from Pittsburg to Brookville is about 700 feet and in Cabell, on the Ohio, it is 680 feet. The Freeport sandstone, 50 feet or more in thickness, is hard and in part pebbly, at times reaching below the second coal bed. The third bed is near the place of the Lower Kittanning and the two beds at the bottom are in the Pottsville.

Eight or 10 miles north from Burning Springs, Stevenson measured the following section:

	Feet
1. Shaly sandstone	20
2. Red shale	105
3. Shaly sandstone	30
4. Red shale	55
5. Sandstone, shaly to massive	65
6. Chert	5 to 12
7. Shale with nodular limestone	9
8. Black shale	3
10. Coal bed [Upper Freeport]	1
11 Shale and sandstone	120

The Ames limestone should be in the lower part of the upper red shale, which is in the place of the "Big Red" of Washington county, Ohio, but it was not observed. The black shale overlying the coal is rich in fossils similar to those obtained by the writer 35 years ago from shales overlying the Upper Freeport near Morgantown. The coal is evidently the Upper Freeport and the sandstone is in the Mahoning interval. The presence of the chert in this position accompanied by the fossiliferous shales was regarded by Stevenson as proving the identity of the Upper Freeport with the Stockton of the Kanawha region.

Roane county is south from Wirt and west from Calhoun. The Pittsburg coal bed can not be identified with certainty, but at Spencer, 15 miles south from Burning Springs, the Washington coal bed of the Dunkard formation is present in the hills. The place of the Pittsburg is taken to be 474 feet below this coal bed on top of a sandstone 38 feet thick. In Ritchie county the interval is 494 feet.

Three sandstones are recorded at Spencer; the first, beginning at 470 feet below the assumed place of the Pittsburg, is 130 feet thick and 30 feet above a second, which is 20 feet thick. The third begins at 718 and is in the Pottsville. No trace of coal is here, but black slate at 660 to 688 feet below the Pittsburg may hold the carbonaceous material of the Brookville horizon. These sandstones are recognizable in wells 6 and 10 miles southeast from Spencer, in one 6 miles east and in that on Yellow creek, though of course, like all sandstones, they vary greatly in thickness and so in the upper and lower boundaries. In the well 6

miles east the upper sandstone begins at 70 feet lower than at Spencer and underlies 90 feet of red rock, most of which belongs in the Allegheny. A coal bed 2 feet thick is here, which, according to the relations assumed at Spencer, should be 558 feet below the Pittsburg. The record shows a coal bed 4 feet thick at 550 feet above it, which may be the Pittsburg coal bed. At 25 miles southeast from Spencer and 10 miles northwest from Clay Courthouse, a great sandstone occurs, practically continuous for 335 feet, being broken by only three shale beds in all 30 feet thick. This is evidently the mass termed by Mr Campbell the Charleston, which in its lower portion is Allegheny and in its upper Conemaugh.

In Jackson county, west from Roane and Wirt and south form Wood, the records can not be interpreted by the writer. Mason county is west from Jackson and adjoins Meigs and Gallia of Ohio. On the eastern border, which is 10 miles southeast from Pomeroy, Ohio, the Mahoning sandstone ends at 465 and the first Pottsville sandstone is at 685 feet below the Pittsburg coal bed. The Allegheny, about 200 feet thick, contains two sandstones 85 and 50 feet thick, but no trace of coal. Twelve miles southwest, on the Ohio river opposite Gallipolis, a coal bed is present at 422 feet, a sandstone 67 feet thick begins at 532 feet, and a coal bed ends at 669 feet below the Pittsburg, resting on a great double sandstone, 413 feet thick, extending to within 45 feet of the "Big Lime." The bottom coal bed is at the Brookville horizon, but the relations of the upper bed are uncertain.

In Putnam county, southeast from Mason, one has at Winfield, 27 miles southeast from Gallipolis, the complete record reported by Mr Campbell and Doctor White. A sandstone 70 feet thick begins at about 540 feet below the Pittsburg and rests on slate and coal 20 feet, reaching to sandstone beginning at 629 and ending at 735 feet below the Pittsburg. These sandstones represent the lower portion of the mass seen near Charleston, the upper portion being replaced in great part by shale. The Brookville coal bed is not noted in the record, but it belongs not far from the bottom of the sandstone, for at lock number 6, 20 miles southeast from Winfield and 5 miles northwest from Charleston, it is about 750 feet below the Pittsburg and underlies a sandstone, 405 feet thick, extending almost 200 feet into the Conemaugh. In a boring about 12 miles southwest from Winfield a coal bed is reported at 750 feet above the "Big Lime" underlying a sandstone, 105 feet thick, with no higher sandstone within 300 feet. This may be the Brookville, whose place at

* Geology of West Virginia: Wirt, vol. i, p. 262; vol. *ia*, pp. 464-465, 467-468; Roane, vol. i, pp. 264, 268; vol. *ia*, pp. 470, 472; vol. ii, pp. 398-399.

J. J. Stevenson: Proc. Am. Phil. Soc., 1875, vol. xiv, p. 395.

Winfield is somewhat less. It is evident that the sandstone of the Kanawha region is becoming replaced by shale.

Cabell adjoins Putnam at the west and reaches to the Ohio river opposite Lawrence county of Ohio. In the absence of surface measurements, it is difficult to interpret the well records in the eastern part of the county, but on the west side, at Central City, is a record directly referable to the Pittsburg coal bed, which is mined in hills overlooking the river only 10 or 12 miles away from its outcrop on Greasy ridge, within Ohio. There the Brookville horizon is marked by 10 feet of black shale ending at 680 feet below the Pittsburg coal bed and underlying a double sandstone in all 105 feet, but divided midway by 50 feet of shale. This represents the lower part of the mass at Charleston. At Greenbottom, on the Ohio near the northern edge of the county, a coal bed is recorded at 832 feet above the "Big Lime." At Central City the Brookville is 630 feet and at Gallipolis, 15 miles northwest from Greenbottom, 458 feet above that limestone. The coal bed at Greenbottom must be at least 250 feet above the place of the Brookville and therefore in the Conemaugh.*

Beyond the Kanawha river the massive sandstones of the Allegheny have resisted erosion, so that they cap the high hills of western Fayette, northwestern Raleigh, northwestern Wyoming, and probably enter Buchanan county of Virginia. One should expect to find the formation in Pike county of Kentucky. The rocks fall toward the northwest, and the Upper Freeport (Mason) and Brookville (Stockton-Lewiston) coal beds have been followed with more or less certainty across the counties of Boone, Fayette, Lincoln, Wayne, Logan, and Mingo to the Kentucky line; but the relations of the coal beds are somewhat indefinite, as the sandstones are variable, limestone is wanting, and the Black Flint disappears very quickly beyond the Kanawha river. Much work has been done within this area, but the section has not been carried in detail, so that the more or less tentative correlations by the several observers are not wholly in accord.

Mr d'Invilliers obtained a measurement in northern Raleigh, on Marsh fork of Coal river, about 25 miles southwest from the mouth of Gauley river:

	Feet.	Inches
1. Coal bed	7	4
2. Interval	51	0
3. Coal bed	3	8
4. Interval	126	0

* Geology of West Virginia: Mason, vol. i, pp. 281-282; vol. ii, p. 412; Putnam, vol. ii, pp. 401-402, 483; Cabell, vol. i, p. 275; vol. *ia*, pp. 484, 488, 490-494.
M. R. Campbell: U. S. Geol. Survey folios, Charleston, p. 3; Huntingdon, p. 3.

	Feet.	Inches
5. Coal bed	9	11
6. Interval	141	0
7. Lewiston coal bed	5	10
8. Interval	123	0
9. Coal bed	3	8
10. Interval	184	0
11. Winifrede coal bed	4	0

The identification of the Lewiston and Winifrede beds is taken by Mr d'Invilliers to be correct, but the relations of the other beds are very uncertain. The intervals seem to suggest that coals numbers 1 and 3 belong to the Conemaugh. No measurements are available for 18 miles down the river, where one finds what appears to be the Brookville-Stockton bed, 4 feet thick and underlying 155 feet of sandstone and shales. A somewhat higher bed was seen by Mr Campbell at 6 miles south from Charleston, belonging at the horizon of the Black Flint, while at a little distance away is a bed thought by him to be near the place of the North Coalburg. Mr Campbell does not find the number 5 Block coal here, though he recognizes it at a short distance eastward.

In northeastern Lincoln county, on Cobbs creek, a branch of Little Coal river, Mr d'Invilliers measured:

		Feet.	Inches
1. Sandstones, shales, and red beds		400	0
2. Coal and shale		6	0
3. Sandstone		35	0
4. Coal bed		Blossom	
5. Sandstone, fine conglomerate at bottom.		60	0
6. Coal bed and partings, splint		4	3
7. Massive sandstone	35 to	45	0
8. Coal bed, splint, about		4	0
9. Sandstone		40	0
10. Coal bed		3	6

At 3 or 4 miles farther down the river, Mr Campbell found three coal beds, 54, 30, and 97 inches thick, partings included, separated by intervals of 120 and 20 feet. He places the lowest coal near the horizon of the Black Flint, in this agreeing with Mr d'Invilliers, who is inclined to look for the place of the Flint at a little way above his lower splint bed. The highest bed in each case is close to the place of the Upper Freeport.

The Guyandotte flows northwardly across western Lincoln. Mr Campbell reports an important coal bed in the southern part of the county, coming up from the river near Sheridan. His measurements and those made many years ago by Dr. John Locke show it is about 5 feet at Sheridan, but increasing southwardly, so that at one locality it is about 10 feet without serious partings. Mr Campbell places this at about 70 feet below

the top of his Charleston sandstone, so that it seems to be near the Upper Freeport horizon. At Sheridan the upper part is cannel. A lower bed arises from the river above Sheridan, and at 7 miles from that place is 115 feet above the river. Twelve miles farther south, on Stone Coal branch, in Logan county, Mr d'Invilliers finds a coal bed 5 feet 6 inches thick at a little more than 500 feet above the Campbells Creek (Sharon) coal bed. This is 712 feet above the river and it may be the same with Mr Campbell's lower bed. The section at Dingess, in Mingo county, makes possible that this is at the Brookville horizon.

Twelve-pole creek flows northwardly through Wayne county, both forks rising in Mingo county. Mr Campbell finds the upper horizon in his Charleston persistent in the southwest corner of Wayne, where the coal was opened at Radnor, Ferguson, and elsewhere, but proved to be worthless. Doctor White states that this bed rises from the creek at a little way above Wayne. He describes it as double on Cave creek, where the splits are separated by 30 feet of sandstone. This bed, which he correlated with the Upper Freeport, becomes cannel westwardly from Twelvepole creek and the cannel persists to the Kentucky line. Mr Campbell finds another coal bed at 100 feet lower, also poor, and one still lower is shown near the Kentucky line. All of these coals are so badly broken by partings as to be practically worthless.

At Dingess, in northern Mingo, Doctor White describes a coal bed 8 feet 1 inch thick in seven layers of coal and shale and about 480 feet above the Warfield (Sharon) coal bed. It is near the place of the Brookville, for at a few miles west, in Lawrence county of Kentucky, the Warfield (Sharon) coal bed is about 680 feet below what appears to be the Upper Freeport limestone. The section near Nolan, 10 miles farther south, as given by Doctor White, is:

	Feet.	Inches
1. Sandstones and red shale	290	0
2. Mason coal bed	2	1
3. Concealed and coarse sandstone	60	0
4. Number 5 Block coal bed, mostly splint	3	11
5. Fireclay and mostly coarse sandstone	150	0
6. Stockton coal bed, splint, with parting	2	0

One is here on the border and the conditions are very like those observed along the southeast outcrop northwardly beyond the Kanawha.*

* E. V. d'Invilliers: Geological report on West Virginia and Ohio railroad line, pp. 9, 46, 48; map of New river and Kanawha coal field; also personal communication of unpublished material.

B. S. Lyman: Proc. Am. Phil. Soc., vol. xxxiii, pp. 286-288.

M. R. Campbell: Charleston folio, pp. 6, 7, 8; Huntingdon folio, pp. 4, 5, 6.

I. C. White: West Virginia Survey, vol. ii, pp. 376-377, 541-543.

Conemaugh Formation

CORRELATION

The southern limit of the Conemaugh can not be determined in the present state of our knowledge, but there seems to be little room for doubt that the lower members of the formation are present as far south as Pike county of Kentucky, southwest from Mingo county of West Virginia. Owing to the absence of any beds of coal, limestone, or iron ore possessing economic value in any considerable area, the Conemaugh has been regarded as "barren," but its coal and some other horizons prove to be quite as persistent as those of the other formations and its variations are quite as interesting as those of the Pottsville. The interval between the Upper Freeport and the Pittsburg coal bed decreases westward from about 600 feet along the northerly outcrop in Pennsylvania to about 300 feet along the western outcrop in Ohio and to somewhat less in Kentucky, if one may draw conclusion from the portion remaining in that state.

The noteworthy horizons in the Conemaugh are numerous, but, owing to abrupt variations in character and thickness of the detrital beds, there has been some confusion respecting the relations. The succession in descending order is:

Little Pittsburg limestone.
Little Pittsburg coal bed.
Little Clarksburg coal bed.
Morgantown sandstone.
Elk Lick coal bed.
Washington reds.
Ames limestone.
Harlem coal bed.
Pittsburg reds.
Barton coal bed.
Cowrun sandstone.
Anderson coal bed.
Cambridge limestone.
Buffalo sandstone.
Brush Creek limestone.
Brush Creek coal bed.
Upper Mahoning sandstone.
Gallitzin coal bed.
Mahoning limestone.
Lower Mahoning sandstone.
Uffington shales.

The Pittsburg limestone of H. D. Rogers consists of one or more beds within an interval of about 25 feet below the Pittsburg coal bed, the

higher one often almost directly under that coal. Sometimes these limestones are brecciated and they frequently contain minute univalves, whose relations have not been determined.

The Little Pittsburg coal bed of H. D. Rogers refers to a horizon rather than to a single coal bed. At varying intervals down to 50 feet below the Pittsburg coal bed, one or at times two coal beds are seen, usually thin, but occasionally, as in the case of the Jeffers (E. B. Andrews) in southern Ohio and possibly in western Maryland, attaining local importance. Non-fossiliferous limestone is present in some localities associated with the coal.

The Little Clarksburg coal bed of I. C. White, frequently accompanied by a limestone, is a well marked horizon at 100 to 130 feet below the Pittsburg; but it is confined to southern Pennsylvania and northern West Virginia, being unrecognizable at any considerable distance west from Chestnut hill, in the former state. Like many other coal beds, its only representative at times is a black shale containing fragmentary remains of fishes.

The Elk Lick coal bed of J. P. Lesley (Barton of Pennsylvania reports L and K) is an important bed at the type locality in Somerset county of Pennsylvania. The horizon is marked by a thin coal bed at many localities in Pennsylvania and northern West Virginia, while in Ohio it oftens carries thin coal or black shale. Its place is well defined on the east side of the basin, as it underlies the rather persistent Morgantown sandstone. On Elk creek it overlies the Elk Lick limestone, but that bed is uncertain elsewhere, having been observed very rarely outside of Somerset county.

The Ames limestone of E. B. Andrews (Crinoidal of northern Ohio. Green Fossiliferous and Crinoidal of Pennsylvania) is one of the most persistent and in some respects the most remarkable horizon in the Conemaugh. It is wanting, or perhaps not recognized, in the northern portion of the first and second bituminous basins of Pennsylvania, but is present in the southern portions of those basins in Pennsylvania, Maryland, and West Virginia. Though thin, seldom more than 6 and often less than 3 feet thick, it has been followed in exposed sections from Barbour county of West Virginia along the eastern and northern outcrops in Maryland and Pennsylvania into Ohio, where it persists along the western outcrop to the last exposure of its place near the Kentucky line; and in this last state it may be the fourth fossiliferous limestone of Professor Crandall's sections, which is present certainly as far south as the middle of Lawrence county. Southward from Barbour county of West Virginia, along the eastern outcrop, it has not been reported, but Doctor White has identified it with the Two-mile limestone near Charleston, a

fresh-water limestone associated with deep red shales. Whether or not it is present in the central counties of the state, where its place is deeply buried, can not be determined, as the oil-well records can not be depended on for recognition of thin limestones; but it is certainly present under the Cowrun anticline along the central part of the basin in Washington county of Ohio, Pleasants, Wirt, and Ritchie of West Virginia and it is also present in northern Wayne of the latter state, near the Kentucky line. The color is usually greenish, but often masked by iron stain, and the percentage of silica is often large, though the bed is reported as cherty at no place where the indentification is complete. The fourth limestone is cherty in Lawrence county of Kentucky, where one is near its place of disappearance, for at a few miles farther it is represented by only a green calcareous sandstone. The Ames limestone carries a marine fauna at all localities where it has been recognized certainly. In northern West Virginia, for 30 to 40 miles southward from the Pennsylvania line, fossiliferous shales of considerable thickness underlie the Ames, which is the highest horizon in the Appalachian basin at which marine life flourished.

The Harlem coal bed of J. S. Newberry (*7b* of northern Ohio, Crinoidal of Pennsylvania, Friendsville of Maryland) is not so persistent as the Ames limestone, but is present at nearly all localities in Ohio where its place is exposed, is reported frequently along the northern outcrop in Pennsylvania, but more rarely along the eastern outcrop, though the horizon is marked by thin coal or black shale at many localities apparently as far south as Upshur county of West Virginia. Many oil records note it as coal or black shale and it is present as a coal bed under the Cowrun anticline in Washington of Ohio and Wirt of West Virginia. It may be the Coal 12 of Kentucky. Usually it is very thin, but occasionally, as at the type locality in Carroll county of Ohio, it is of workable thickness. For long distances it underlies the Ames limestone directly and it is known as the "Fossil coal" at two widely separated localities, one in Ohio, on the northwestern outcrop, and the other in central West Virginia. At both the upper part of the bed contains fine specimens of mollusca characterizing the overlying limestone.

The Barton coal bed of P. T. Tyson (Bakerstown of Pennsylvania and Maryland, not Barton of Lesley and Stevenson, which is Elk Lick) is a well marked horizon a little above midway between the Ames and Cambridge limestones and above the Cowrun sandstone. Coal is at this place in western Maryland and in most of the counties in western Pennsylvania, but it is rare in Ohio. It may be represented by the Patriot (E. M. Lovejoy) and Slate (E. McMillin) coals of southern Ohio,

but it seems to be wanting in Kentucky, though it may be represented by Coal 12. The Barton coal is rarely of economic importance.

The Anderson coal bed of E. B. Andrews (Norwich of northern Guernsey, Ohio) has been taken for the Barton (Bakerstown) in some portions of Pennsylvania and West Virginia. It seems to be wanting on the east side of the basin, the most easterly locality being in southern Butler of Pennsylvania; thence to the Ohio line it is utterly insignificant. It becomes distinct in Brooke county of northern West Virginia, whence through Ohio it is persistent into Kentucky, where it is the Coal 11. It is a few inches to 15 feet above the Cambridge limestone in Ohio, but the interval increases to between 30 and 40 feet in Kentucky. The bed is of economic value in only a small area within central Ohio.

The Cambridge limestone of E. B. Andrews (Pine creek of western Pennsylvania) is probably the same with a limestone at about 50 feet below the Ames in the second bituminous basin of Pennsylvania as well as in northern West Virginia just west from Chestnut hill and in western Maryland; but it is first clearly recognizable along the northern outcrop in Armstrong county of Pennsylvania, where in many respects it resembles the Ames. Its occurrence as far as Beaver county is a little irregular, but thence along the western outcrop through Ohio into Kentucky it is as persistent as the Ames. The interval between these limestones varies from 90 to 130 feet along the northern and western outcrops. The Cambridge limestone is present at the southwest corner of West Virginia, but it seems to be wanting under the Cowrun anticline, even in Washington county of Ohio. It is persistent only on the west side of the basin, the occurrence on the east side being very irregular. The bed is much more variable than the Ames. In Pennsylvania the color is from dark to gray; in northern Ohio from gray to blue and often weathers buff; while farther south it is a dark limestone associated with dark shales; yet in some portions of southern Ohio it is the "White fossiliferous" limestone. In Noble county of Ohio a new limestone appears directly over the Anderson coal bed, and thence southward there are two Cambridge limestones, 10 to 30 feet apart, designated as Upper and Lower by Professor Edward Orton, one or the other being absent at times for several miles. The Lower is the Cambridge limestone proper, equivalent to Doctor I. C. White's Pine creek. Unlike the Ames, both beds tend to be cherty toward the south. In Kentucky the interval between the Cambridge limestones increases to about 50 feet, with the Anderson at about one-third of distance below the Upper. This limestone carries a rich marine fauna in Ohio and western Pennsylvania, as also in West Virginia at many places north from the Baltimore and Ohio railroad and

in western Maryland; but no fossils were seen in the second basin within Pennsylvania.

The Brush Creek limestone of I. C. White (not Brush Creek limestone of Ohio, volume v), separated from the Cambridge in its type area by the Buffalo interval of 30 to 60 feet, is the Black Fossiliferous limestone of the Pennsylvania reports; it is widely distributed in Pennsylvania, Maryland, and northern West Virginia, but it quickly disappears westward in Ohio and is wanting in the greater part of that state as well as in Kentucky. Professor Newberry found it occasionally in Columbiana county of Ohio and Professor Orton discovered it at one locality in Guernsey county, 40 or 50 miles toward the southwest. Originally it may have been continuous between these localities and may have been removed during deposit of the coarse overlying rock. The limestone is dark, sometimes nodular, carries an abundant marine fauna, and is associated commonly with black fossiliferous shales.

The Brush Creek coal bed of I. C. White (in Pennsylvania, Dudley of Broad Top, Rose of Somerset; Groff and 7 of northern Ohio, Brush creek of southern Ohio; Masontown and Mason in northern West Virginia) is even more persistent than the Harlem around the border of the basin. It has been recognized in Broad Top, in Maryland, in northern West Virginia, in all of the counties of Pennsylvania where its place is exposed, and it seems to be equally persistent in Ohio; but it seems to be wanting under the Cowrun anticline and it can not be recognized in the oil-well records. Mr McMillin's section in Lawrence county of Ohio shows the bed double, with the splits 24 feet apart. This coal bed can not be recognized in the sections of northern Kentucky. Coal 10 of Professor E. R. Crandall underlies the Lower Cambridge directly; it rests on the Buffalo sandstone and is very thin. The horizon is a new one, of which no trace appears in the Ohio sections. At one locality only is there any trace of coal at the Brush creek horizon; that is in southeast Carter county certainly 23 miles from the Ohio and on the extreme western outcrop.

Little reference has been made to the apparently anomalous section of Somerset county within the first bituminous basin of Pennsylvania. There the Conemaugh contains a large number of coal beds and limestones, some economically important, most of which can not be correlated with beds farther west. For the description, the reader is referred to pages which follow. Efforts to recognize these beds led to errors in counties farther west. The Rose coal bed of Somerset is the Brush creek, and above it at a little distance is the Philson, possibly a split from the Rose

or perhaps representing at the east a horizon which at one place in western Pennsylvania shows a trace of coal.

Several sandstones have been recognized and have received names. The Connellsville sandstone of J. P. Lesley seems to be fairly persistent, as sandstones go, along the eastern side in Fayette and Westmoreland counties of Pennsylvania as well as in West Virginia; but the name is useful chiefly to designate the interval between the Little Pittsburg and Little Clarksburg coal beds. One usually finds some sandstone in this interval, often thick and sometimes conglomerate. The Morgantown sandstone of J. J. Stevenson is a more noteworthy deposit in the interval between Little Clarksburg and Elk Lick coal beds. This is remarkably persistent in the eastern half of the basin, and not infrequently some sandstone is present in this interval at Ohio localities. It varies greatly in thickness, at times extending upward as sandstone into the Connellsville interval or downward to below the Ames limestone, while again the whole interval is occupied by shale. Ordinarily it is moderately coarse, at times even conglomerate, and usually so well cemented as to be a durable building stone. It is the first oil rock of Greene county, Pennsylvania. Somewhat lower down is the Cowrun sandstone of the Ohio oil-well drillers overlying the Anderson coal bed. It marks the interval between the Barton coal bed and the Cambridge limestone. This interval frequently shows massive sandstone along the northern outcrop, at times continuous with the Buffalo sandstone below. Like all the other sandstones, this is variable and often absent. It has been a somewhat important oil horizon in Ohio and has yielded some oil in West Virginia, where the drillers' records often note it under the name "Salzburg" sandstone. The Buffalo sandstone of I. C. White (Salzburg of Stevenson) is in the interval between the Cambridge and Brush Creek limestones. The type locality is in southwest Armstrong county, where the mass is 60 feet thick and conglomerate. It is persistent along the northern and eastern outcrop in Pennsylvania and in West Virginia and a sandstone is usually shown in this interval by the oil-well records of the latter state. Along the western outcrop in Ohio and in Kentucky this interval usually contains more or less of coarse sandstone.

The Mahoning interval, between the Brush Creek and Upper Freeport coal beds, is occupied typically by the Upper and Lower Mahoning sandstones, separated by variable shales, but at times one finds the whole interval filled with shale, at others with sandstone. In much of Pennsylvania and West Virginia both sandstone plates are present, but on the western side of the basin throughout the upper plate and most of the intervening shale disappear, so that the Brush Creek coal bed comes down

almost to the Lower Mahoning sandstone. The shale separating the sandstone plates varies greatly in thickness within the first and second bituminous basins of Pennsylvania as well as for almost 20 miles west from Chestnut ridge, in that state, and to this variability are due some of the errors in reports upon that area.

The Gallitzin coal bed of Franklin Platt (Mahoning of western Pennsylvania, not Brush creek of Ohio) is confined to the eastern side of the basin and is in the shales overlying the Lower Mahoning. It may be single, double, or even quadruple. It overlies the Mahoning limestone of I. C. White (not Mahoning limestone of H. D. Rogers), which is divided as is the coal bed, so that the Upper Gallitzin coal may be accompanied by an Upper Mahoning limestone. The Upper Gallitzin coal bed was mistaken for the Philson of Somerset county by W. G. Platt in Indiana and Jefferson counties and by Stevenson in the Ligonier valley, for there the shales are so thick that the Upper Gallitzin is as far above the Upper Freeport as is the Rose (Brush creek) in Somerset. The synonymy is:

Gallitzin coal bed..............	Speer of Broad Top, Mahoning of western Pennsylvania.
Upper Gallitzin	Philson of Indiana and Jefferson counties, and Ligonier valley of Fayette and Westmoreland counties.

The Gallitzin beds disappear in western Pennsylvania along with the Upper Mahoning, and the Brush Creek coal bed is let down to the Mahoning limestone, which in volume v of the Ohio reports is referred to the Brush Creek limestone. This Mahoning limestone is widely distributed either as limestone or calcareous iron ore, but especially along the northern and western sides of the basin.

The Lower Mahoning sandstone is more persistent than the Upper. It is the Mahoning sandstone of most of the reports on counties west from Chestnut hill in Pennsylvania and is the only member present in Ohio and Kentucky. It is the "Dunkard" sandstone of most of the well records, though the Upper Mahoning appears under the same name in many records from the east side of the basin.

Along the southeastern outcrop within West Virginia the rocks of the lower Conemaugh become very coarse, and there is an almost continuous mass of more or less conglomerate sandstone from the bottom of the Allegheny, 400 feet being recorded in one well below Charleston. This condition disappears for the Conemaugh as for the Allegheny within a very few miles toward the northwest; but in some localities, far away from the coastline and in the very middle of the basin, one finds sandstone the

prevailing rock throughout the section. A similar condition has been noted for the Allegheny.

Underlying the Mahoning and separating it from the Upper Freeport coal bed is a shale, the Uffington shale of I. C. White. It is not persistent, having been removed from wide areas during deposit of the overlying sandstone. Near Morgantown, in northern West Virginia, it is crowded with marine forms which are abundant even at contact with the coal; elsewhere except in Upshur and Wirt counties the fauna seems to be wanting, but the shales have yielded many plant remains.

The reappearance of red and green shale much resembling that of the Shenango beds of the Lower Carboniferous at the top of the Allegheny was noticed on a previous page. In the Conemaugh formation, red shale occurs within the Mahoning interval in Gilmer, Ritchie, Calhoun, and Wood counties of West Virginia, where some wells show a great thickness, the whole interval being filled and the mass being continuous with reds above. A bed 25 feet thick in Wetzel county may belong in its lower part to the Upper Mahoning, and thin streaks referable to this interval are reported in Greene and Washington counties of Pennsylvania. The only occurrence in Ohio is a bed 10 feet in Tuscarawas county resting on the Lower Mahoning, but this may belong to the next interval above, as the Upper Mahoning is not present in Ohio. Practically the reds of the Mahoning are confined to the four central counties in West Virginia.

Reds of the interval between Mahoning and the Cambridge limestone are more widely distributed. They are thick and variable in Ritchie and Wood, very thick in Calhoun, less thick in Jackson and Clay, all of them in the central area. These reds are found elsewhere in widely separated localities—Wetzel, Webster, Brooke, and Ohio of West Virginia; Cambria, Indiana, and Westmoreland of Pennsylvania, and occasionally in the Hocking valley of Ohio. The distribution in this interval is certainly much wider than in the Mahoning interval, but away from the central area in West Virginia their occurrence is very irregular and for the most part the beds are very thin; but in the next interval, between the Cambridge and Ames limestones, one finds a great expansion. Immediately below the Ames or, if present, the Harlem coal bed is the mass termed by Doctor White the Pittsburg reds, which is so widespread that it deserves to be ranked with the most persistent beds of other types. In the central area—Lewis, Gilmer, Roane, Ritchie, and Jackson of West Virginia—the Pittsburg reds are very thick and at times continuous with the Washington reds above the Ames limestone, while in several of those counties there are still lower beds within this interval. In Calhoun and Wood counties the Pittsburg reds are less important than in the other

mentioned, but the beds are thick in southeast Washington and portions of Meigs and Gallia of Ohio and they seem to be present in Boyd of Kentucky. Apparently, however, they are absent in Lawrence of that state, as they are not shown in any of Professor Crandall's numerous sections. Along the western outcrop in Ohio the reds of this interval are wanting or very thin until one approaches the northern border in Jefferson and Columbiana counties, where Newberry reports 50 feet. They are somewhat irregular along the northern outcrop and in the first bituminous basin are rarely seen, and when present are very thin, but they are present and well marked in most of the counties west from Chestnut hill. They seem to be wanting in the northeast corner of the West Virginia field, but are rarely wanting in the northern counties of that State. Reds of all horizons are practically absent from the first bituminous basin of Pennsylvania and are insignificant in the second.

Immediately above the Ames is another deposit, known to the Ohio drillers as the "Big Red," which may receive as a geographical designation the name Washington reds, its stratigraphical importance having been recognized first in Washington county of Ohio. In the central area—in Lewis, Gilmer, Ritchie, and central Roane of West Virginia—the mass is thick, at times apparently continuous with the Pittsburg reds below and not rarely extending upward into the Morgantown interval. Away from this area, eastwardly and northwardly, it is irregular; it seems to be wanting along the eastern outcrop, is indefinite northwestwardly toward the Panhandle, but is well marked in Marion and Monongalia counties, one well showing it evidently continuous with the Pittsburg reds and another showing it extending into the Morgantown interval. It is reported in one Washington County well, but elsewhere in Pennsylvania it seems to be wanting except in northern Allegheny. West from the area of greatest development it is not reported in the wells of Wood and Jackson, but in Pleasants, north from Wood, it is thick, while in Washington of Ohio, adjoining Pleasants of West Virginia, it is from 74 to 100 feet thick; thence westwardly and southwestwardly it is thin and irregular, but northwestwardly it persists into Muskingum county, where it is usually thin, though 60 feet thick at one locality; thence northwardly it is evidently absent.

The interval between the Morgantown sandstone and the Pittsburg coal bed frequently shows red beds, but these are extremely irregular in thickness and distribution. They occur especially within the central area, already referred to, where sometimes they are continuous with the Washington, while in many wells within Ritchie, Calhoun, Roane, and Jackson the reds of this interval are almost or altogether continuous with a

higher horizon which, notably in Wood of West Virginia and Washington of Ohio, extends well up into the Monongahela; but in probably by far the greater portion of the Conemaugh area red beds are wholly absent above the Morgantown sandstone.

The horizontal expansion of the reds reached its maximum during the interval between the Cambridge and Ames limestones, reaching then even to the southeastern outcrop, as it exists today; thenceforward the area constantly decreased until toward the close of the Conemaugh it included only the several counties of West Virginia spoken of as the central area. The conditions prevailing during deposit of the Pittsburg reds did not return until well on in the Dunkard formation.

The non-conformabilities within the Conemaugh are not great in absolute measure, but they are proportionately great, for the formation loses half its thickness in passing from the east to the west side of the basin. This is in accord with conditions observed in the earlier formations, the extent of subsidence decreasing toward the west. But while this decrease is noticeable in all of the intervals it is especially noteworthy in the Mahoning and Morgantown, the Upper Mahoning being unrepresented in Ohio and the Morgantown being insignificant, so that the Ames limestone remains in Ohio, as in Pennsylvania, almost midway between the Upper Freeport and Pittsburg coal beds.

EAST FROM THE ALLEGHENIES

The Conemaugh is somewhat more than 500 feet thick in the Broad Top coal field, but above the Mahoning it is ill-exposed and available details are few. A coal bed, 2 to 4 feet thick, known in Huntingdon county as the Dudley, occurs at a few feet above the Mahoning in all parts of the field and is about 400 feet below the bed there accepted as the Pittsburg. In Huntingdon it underlies a massive sandstone, but in Bedford the overlying rock for 30 feet is shale. The Mahoning is double, the section in Bedford county being

	Feet
Sandstone	50
Coal bed	1
Clay	3
Sandstone	40

The upper plate varies from coarse grained and somewhat conglomerate to fine grained and even shaly, but the lower plate, 25 to 40 feet thick, is usually massive and conglomerate, sometimes almost wholly made up of white quartz pebbles. The coal bed known as the Speer in Bedford county occasionally becomes workable, but it disappears northward and

appears to be absent from Huntingdon county. This bed is at the Gallitzin horizon and the Dudley is at that of the Brush Creek.*

The Georges Creek and Potomac area is farther southwest, beginning in Bedford and Somerset counties of Pennsylvania and continuing across Maryland into West Virginia. The observations in Pennsylvania are somewhat conflicting, but the sections are clear in the other states. The intervals at Barton in Maryland are:

	Feet.	Inches
1. Pittsburg coal bed		
2. Shales, sandstone, and concealed	143	9
3. Franklin coal bed and partings	6	10
4. Shales, sandstone, and concealed	259	0
5. Bakerstown coal bed	3	0
6. Concealed and sandstone	92	0
7. Masontown coal bed	1	7
8. Shale and sandstone	51	5
9. Sandstone	33	6
10. Shale	3	6
11. Upper Freeport coal bed		
Total	594	7

The Franklin, or "Dirty Nine-foot," coal bed is thought by Doctor Martin to be at the Little Clarksburg horizon. The Bakerstown is evidently the Barton of Tyson; farther southwest, at Blaine, it is about 357 feet below the Pittsburg and about 90 feet above the Masontown, which is the Brush creek. This lower bed at Blaine underlies the fossiliferous Brush Creek limestone, which is associated with its characteristic black shale.

The horizon of the Mahoning coal bed is marked at many places by coal seldom more than 20 inches thick, and at one locality in West Virginia Doctor White saw a great thickness of limestone at the Mahoning horizon. The Brush Creek coal bed is thoroughly persistent, usually less than 2 feet thick, though at times yielding nearly 3 feet of coal and in one instance swelling to a mass 9 feet thick, with five benches of coal 3 feet 8 inches in all. At one locality it shows 1 foot of coal underlying 5 feet of black shale with coal streaks, while at another the upper part for 2 feet 5 inches is an alternation of bone, slate, and coal. The Barton is variable, but locally becomes thick and good. The variations in this bed, as shown by figures in volume v, are worthy of careful study, for the bed varies from apparently solid coal 3 feet thick to a double, triple, or even quadruple bed with thick bone at top or bottom, while at times it is a

* J. J. Stevenson: Bedford and Fulton counties (T 2), pp. 242, 659-662.
I. C. White: Huntingdon county (T 3), pp. 47-50.

mass of black shale with only thin streaks of coal. All of these changes appear within an insignificant area.

The Harlem (Friendsville) coal bed has been recognized in the northern, or Georges Creek, region at about 100 feet above the Barton, but it is very thin. The Elk Lick coal bed and another a few feet higher seem to be equally persistent. The Franklin, certainly very near the Little Clarksburg horizon, shows variations as abrupt and as interesting as those of the Barton and Brush Creek. A bed at 50 to 90 feet below the Pittsburg, sometimes divided into two beds, is correlated with the Little Pittsburg of western areas. The unstable conditions still prevail, for the bed is often broken by partings whose thickening leads to distinct division of the bed.

In Tucker county of West Virginia Doctor White finds coal beds at 16, 130, 173, 204, and 404 feet below the assumed place of the Pittsburg coal bed, the lowest being 180 feet above the Upper Freeport. The only limestone is 20 feet thick and 42 feet above the Upper Freeport; therefore at the Mahoning horizon. The lowest coal bed is not far from the place of the Barton, but the relations of the higher beds can hardly be determined in the present state of information.

The exposed sections and bore-hole records show no red shales in the Conemaugh east from the Alleghenies.

Professor Clark and his associates have recognized the Morgantown and Connellsville sandstones as well as the Pittsburg and Clarksburg limestones; whether or not the correlations of the several coals, limestones, and sandstones be absolutely exact is unimportant; they show sufficiently the similarity of conditions east and west from the Allegheny mountains.*

FIRST BITUMINOUS COAL BASIN OF PENNSYLVANIA

The Conemaugh is recognizable in this basin with certainty no farther north than Center county, where a few feet of rock overlie the Upper Freeport coal bed. In Clearfield county Doctor Chance finds the Mahoning at Morrisdale with the Gallitzin coal bed near the bottom and separated by 40 or 50 feet of shaly measures from a coal bed which he correlates with the Upper Freeport. Near Houtzdale, 8 miles southwest, Doctor White's section shows the Mahoning 100 feet thick and holding the

* I. C. White: Geology of West Virginia, vol. ii, p. 235.
C. C. O'Harra: Maryland Survey, Allegany county, p. 119.
C. S. Prosser cited in same, p. 122.
G. C. Martin: Garrett county, pp. 127-128, 134.
W. B. Clark et al.: Vol. v, pp. 307-308, 344, 348-349, 350-368, 372, 376.

Gallitzin. The Mahoning is often represented by pebbly rock in the southern part of the county, but it is mere shale quite as frequently.*

Almost 150 feet of Conemaugh remain in northern Cambria, but exposures for measurement are reached first at Bennington on the Cambria-Blair border, 20 miles south from the Clearfield line. There Mr Platt's section shows a 10-inch coal bed separated by 35 feet of shaly measures from the Upper Mahoning sandstone, 50 feet thick, which overlies a 2 feet 8 inches coal bed, with 55 feet of shaly beds intervening to the Upper Freeport coal bed. The highest coal, 142 feet above the Upper Freeport, seems to be the Brush Creek and the intermediate bed is the Gallitzin. At Gallitzin, a few miles west in Cambria, Doctor White finds the Brush Creek 140 feet above the Upper Freeport; but at Cresson the section shown in a shaft is:

	Feet.	Inches
1. Slates	60	0
2. Sandstone	9	0
3. Fireclay	8	0
4. Sandstone	109	0
5. Coal	1	0
6. Fireclay	9	0
7. Sandstone	17	0
8. Clay, shale, sandstone	34	0
9. Sandstone	33	6
10. Slate and sandstone	14	0
11. Upper Freeport coal bed		

This is not unlike sections in the second basin and one may regard the coal, Number 5, as an upper split of the Gallitzin, the place of a lower split being on top of the fireclay, Number 8.

Mr Fulton's section near Johnstown, in southwest Cambria, shows the Gallitzin at 67 feet above the Upper Freeport with the Mahoning limestone or Johnstown ore at a few feet below it. The Brush Creek coal bed is absent and at 148 feet above the Upper Freeport is a red bed, this being the most northerly locality at which red shale occurs. The section extends upward to 302 feet, but neither here nor at Cresson are there any traces of the Barton coal bed or of the limestones belonging in that interval.†

In the deep Salisbury subbasin of southeastern Somerset county a full section may be compiled from the measurements made by F. and W. G. Platt, which accords somewhat closely with that made by Doctor White

* H. M. Chance: Revision of Clearfield county (H 7).
I. C. White: U. S. Geol. Survey Bull. no. 65, p. 124.

† F. Platt: (T), p. 95; (H 2), p. 61.
J. Fulton: (H 2), p. 97.
A. A. Prosser and D. B. Hardin: Appendix to H 3, p. 369.

in the same area. The Conemaugh is 600 feet thick and contains many coal beds and limestones, several of which can not be correlated with any beds in basins farther west. A sandstone, apparently the Morgantown, and 77 feet thick, rests on the Elk Lick coal bed, which at the typical locality overlies the Elk Lick limestone, 8 feet thick. At about 80 feet lower is a limestone which Doctor White correlates with the Ames. It is from 300 to 320 feet below the Pittsburg coal bed and overlies a thin coal correlated with the Harlem. The Brush Creek coal bed is at 100 feet above the Upper Freeport, and at a few feet higher is a limestone which has been correlated with the Brush Creek. This immediately underlies a thin coal bed, the Philson of W. G. Platt. All of the limestones are non-fossiliferous. These coal beds and limestones seem to be persistent in the northwestern part of the county and 2 feet of red shales are associated there with the Ames limestone, the most northerly appearance of the "Pittsburg reds." Farther south on this west side, near Bakersville, Mr Platt found a dark fossiliferous limestone, evidently the Brush Creek, while still farther south are two limestones, 60 to 70 feet apart, of which the upper is clearly the Ames, as shown by its fossils as well as its physical character, while the lower may be at the Cambridge horizon.

A compiled section in the southwestern part of the county shows the Brush Creek coal bed (Rose of F. Platt) at 263 feet below the Elk Lick limestone and 105 feet above the Upper Freeport. The coal bed underlies black shales with calcareous nodules, representing the Brush Creek limestone and black shale. The intervals decrease southwardly and westwardly; at Confluence, near the western border, the interval between Elk Lick limestone and Upper Freeport is 345 feet, but within five miles eastwardly it increases to 375 feet.*

Passing over into Garrett county of Maryland, one finds Mr Martin's section on Castleman river, in the Salisbury subbasin, and another at Friendsville, in the Johnstown subbasin.

In the former the Little Pittsburg coal bed is present, but without its limestone, and a thin coal bed at 137, the same with that seen by W. G. Platt in Somerset county, may be the Little Clarksburg. The Ames limestone at 328 feet below the Pittsburg is present with all its characteristic features and overlies directly the Harlem coal bed (Friendsville of Martin). The Barton (Bakerstown) coal bed is here and red shales appear 50 feet below it at the horizon of those seen in eastern part of Cambria. The Brush Creek limestone (Lower Cambridge) is dark

* F. and W. G. Platt: (H 3), pp. 23, 40, 63, 76, 179, 223, 239, 244, 258, 266, 282. I. C. White: U. S. Geol. Survey Bull. no. 65, p. 76.

colored and fossiliferous, with, below it, the Brush Creek coal bed at 97 feet above the Upper Freeport.

The Clarksburg limestone is present in the Friendsville section at 39 feet above the Morgantown sandstone, which is 84 feet thick and in part conglomerate. The Elk Lick, Harlem, Barton, Brush Creek, and Gallitzin coal beds are all present, though all are thin, none exceeding 1 foot 9 inches. The Elk Lick, Ames, Cambridge, and Brush Creek limestones are distinct, though the first is practically only calcareous shale, and all except the Elk Lick are fossiliferous. Red shale is associated with the Cambridge limestone at nearly 200 feet above the Upper Freeport. There is much sandstone above the Clarksburg limestone and some of it is conglomerate, representing perhaps the Connellsville sandstone.*

SECOND BITUMINOUS COAL BASIN OF PENNSYLVANIA

Within the Second basin the Mahoning is present in small areas as far north as northern Center county, where it is the protecting cover for the Upper Freeport coal bed. At Karthaus, in Clearfield, Mr James describes it as 72 feet thick, with a 2 feet coal bed, the Gallitzin. Doctor Chance's section in southern Clearfield shows two sandstone plates, 40 and 50 feet respectively, separated by 30 feet of shale, which holds at the bottom the Gallitzin coal bed and the Mahoning limestone, this being the most northerly point at which that limestone has been observed. The lower Mahoning is coarse and at times conglomerate.†

Mr d'Invilliers obtained a number of sections within a small area in northwestern Cambria, which illustrate the variability of the lower part of the Conemaugh. Two of these are:

	Feet.	Inches.	Feet
1. Shales	20	0	20
2. Sandstone	95	0	85
3. Shales	25	0	40
4. Coal bed	0	8	2
5. Shales	35	0	60
6. Sandstone	40	0	35
	215	8	242

In these there are two plates of sandstone, as in southern Clearfield, and in each case a coal bed above the middle. The bottom of the upper plate is at 100 and 137 feet above the Upper Freeport and the coal bed at 75 and 95. In another section the coal bed is at 137 feet, with only

* G. C. Martin: Garrett county, pp. 128, 130, 134-135, 138-139.
† H. M. Chance: (H 7), p. 132.

sandstone in the interval to the Upper Freeport, while in a fourth the bottom of the upper sandstone is at 141 feet, the interval containing aside from shale three thin coal beds at 25, 75, and 141 feet.* The two sandstone plates are apparently the same with those seen near by in Clearfield, but the intervening shales have become thicker, so that the Mahoning in two of the sections is about 220 feet thick instead of 120, as in Clearfield. The several coal beds may be taken as representing the Gallitzin horizon, and in following the section southward this interpretation will be accepted.

In northeastern Indiana county, west from Cambria, Mr Platt found at 4 or 5 miles west from the area of Mr d'Invilliers' sections a coal bed at 90 feet above the Upper Freeport, separated by 40 feet of shale from the massive "Mahoning" sandstone which rests directly on the Upper Freeport. At a mile or so farther west he saw a coal at 60 feet above that coal bed, and at a little distance farther measured this section:

	Feet.	Inches
1. Thin sandstone and sandy shale	47	0
2. Slates	5	0
3. Philson coal bed [Upper Gallitzin]	3	1
4. Concealed	50	0
5. Gallitzin coal [Lower Gallitzin]	3	0
6. Mahoning sandstone [Lower Mahoning]	65	0
	173	1

to the Upper Freeport coal bed, the same with the Cambria condition. No trace of any higher coal bed was seen. About 8 miles farther south and 3 miles west from the Cambria line the section reaches to a massive sandstone which Mr Platt correlates with the Morgantown. It is probable that here, as in northern Westmoreland, that sandstone is continuous downward to the Ames horizon, and that the coal bed here called Elk Lick is in fact the Harlem. At 130 feet below this coal bed is a Black Fossiliferous limestone, 212 feet above the Upper Freeport. The Black limestone overlies a mass of limestone and shale 26 feet thick, its bottom 35 feet above a thin coal bed. The whole mass represents the Brush Creek limestone, while at 65 feet higher is a thin limestone which may be at the Cambridge horizon. The Brush Creek and Upper Gallitzin coals are at 152 and 120 feet above the Upper Freeport. Three or four miles southwest on the Conemaugh river the section is:

* E. V. d'Invilliers: Final Summary Report, pp. 418, 419.

		Feet.	Inches
1.	Shales, with 2 feet red band at 25 feet from top	62	0
2.	Upper Mahoning sandstone .... 20 feet Upper Mahoning shale .... 10 feet Upper Mahoning sandstone .... 15 feet	45	0
3.	Philson coal [Upper Gallitzin]	0	6
4.	Limestone [Upper Mahoning]	5	0
5.	Fireclay, sandstone, rusty shale...............	20	0
6.	Gallitzin coal [Lower Gallitzin]..............	Trace	
7.	Black shale	4	0
8.	Limestone [Lower Mahoning]	4	0
9.	Lower Mahoning, mostly sandstone	55	0

giving 133 feet for the Mahoning, with both Gallitzin coal beds accompanied by limestone. The Brush Creek limestone belongs in the upper half of Number 1.*

This conclusion respecting the relations of the Black Fossiliferous limestone is confirmed by Stevenson's section on the Conemaugh river in Westmoreland county near the Cambria line, where that limestone is 170 feet above the Upper Freeport and 30 feet above the top of the Mahoning. The last consists of two sandstone plates, 45 and 50 feet respectively, separated by 45 feet of variegated clays, in all 140 feet, with the Upper Gallitzin directly underlying the upper plate.† The interval from Upper Freeport to Gallitzin is 25, and that to the Brush Creek limestone is 42 feet less than at 4 miles north in Cambria county. Within a mile or two farther south the Upper Gallitzin is about 50 feet above the Lower Mahoning and 10 feet below the Upper, and the Upper Mahoning limestone underlies it by 6 to 20 feet. The Upper Gallitzin was seen again at 3 or 4 miles southeast, where the Lower Gallitzin is present though only 3 inches thick. Farther south, at 12 miles from the Conemaugh river and still on the east side of the basin, the Ames and Brush Creek limestones were seen, 126 feet apart by barometer, each thoroughly characteristic and the latter overlying the Brush Creek coal bed, 8 inches thick. A coal bed, evidently the Lower Gallitzin, is at 100 feet lower.

An incomplete section obtained midway in the basin near Ligonier shows a Little Pittsburg coal bed at 60 feet below the Pittsburg, resting on its limestone, which is persistent. Another coal, at 140 feet, with an uncertain limestone, may represent the Little Clarksburg horizon. The Morgantown sandstone, beginning at 160 feet and 115 feet thick, extends downward to the Ames horizon, while at 18 feet below it is a coal bed correlated by Stevenson with the Elk Lick. It is the Harlem, and

* W. G. Platt: (H 4), pp. 76, 100, 103, 121, 125, 128.

† The error of correlating the Upper Gallitzin with the Philson of Somerset county affects the work of both W. G. Platt and Stevenson throughout the Second basin.

the fragments of Ames limestone seen below it belong above. Here, as in Cambria county, a limestone 2 feet thick is found at about 50 feet below the Harlem coal, and that coal bed is approximately 223 feet above the Upper Gallitzin (Philson of the text). The Brush Creek limestone is exposed at many places, and at one exposure the Barton coal was seen at 80 feet above it. The Upper Mahoning is usually thin in the southern part of the county and the Lower Mahoning is apt to be shaly. The Upper Gallitzin coal is persistent in this portion of the area and at one locality near the Fayette County line the Lower Gallitzin with the Lower Mahoning limestone is only 36 feet 8 inches above the Upper Freeport.*

In Fayette county, midway in the basin and 6 miles south from the Westmoreland line, the Harlem coal bed (Elk Lick in the text) is 306 feet above the Upper Freeport and overlies the "Pittsburg reds," 20 feet thick. One hundred feet lower is a coarse pebbly sandstone termed Salzburg by Stevenson, 40 feet thick; near by, the Brush Creek coal is at 138 and the Lower Gallitzin at 45 feet above the Upper Freeport. South from the Youghiogheny, on the east side of the basin, the Barton coal was seen at 238, the Salzburg sandstone at 170, and the Brush Creek coal at 138 feet above the Upper Freeport, the Barton being associated with red shale. This Salzburg sandstone is practically equivalent to the Buffalo sandstone of Doctor White and it can hardly include the sandstone overlying the Cambridge limestone. The Gallitzin coal bed, single in this county, is at 50 to 65 feet above the Upper Freeport and its underlying limestone appears occasionally in the sections. The Ames and Brush Creek limestones are present on the west side of the basin. Exposures are few and in most cases imperfect throughout this basin south from Clearfield county.†

In Preston county of West Virginia Doctor White examined diamond drill cores obtained near Masontown about 10 miles south from the state line. One of them shows:

	Feet.	Inches
1. Barton coal bed		
2. Interval to boring	47	0
3. Sandstone	8	6
4. Fireclay and shale	19	0
5. Pebbly sandstone [Buffalo]	54	0
6. Black shale and fossiliferous limestone [Brush Creek]	5	9
7. Coal bed [Brush Creek]	0	9
8. Fireclay, green shale, sandstone, and fireclay...	42	5
9. Sandstone, shaly at bottom	35	4

* J. J. Stevenson: (K 3), pp. 115, 116, 117, 120, 121, 129, 138, 163, 170, 172.
† J. J. Stevenson: (K 3), pp. 67, 84, 91, 110, 113.

to the Upper Freeport. The Barton is 134 feet above the Brush Creek, which is 78 feet above the Upper Freeport. Here the Buffalo sandstone overlies the Brush Creek limestone directly and there is no trace of the Cambridge. Another boring, barely a mile away, shows the Barton only 86 feet above the bottom of the Black fossiliferous shales, which are 104 feet above the Upper Freeport. There also the coarse Buffalo sandstone overlies the black shale; but at 5 miles northwest, in the Third basin, the interval from Brush Creek limestone to the Upper Freeport is but 50 feet. In all of the cores that limestone and its shales are characteristic, both of them black and richly charged with fossils.

The Mahoning is very thick in the northern part of the basin, but becomes thinner southward, while the interval between Brush Creek and Ames limestones, small at the north, increases southward, so that toward the West Virginia line the section becomes comparable with those in the Third basin and beyond.

Measurements by Doctor White at Newburg, 10 miles south from Masontown, show the interval above the Ames to the Pittsburg thicker than in Westmoreland county. The Elk Lick coal bed is at 259 feet below the Pittsburg and the Ames is represented by shales at 344 to 357, with the Harlem coal bed at 357.*

In Preston county the second basin becomes continuous with the third.

WESTERN BITUMINOUS BASINS OF PENNSYLVANIA

The Mahoning is present in small patches within southern Elk county, where it is in two more or less shaly divisions separated by a thin Gallitzin coal bed.†

Mr Platt's report shows scattered areas of Conemaugh in Jefferson county, but except in the eastern portion, near Chestnut ridge, the thickness remaining rarely exceeds 100 feet. In Clarion, west from Jefferson, some insignificant fragments remain, but the exposures are too imperfect for measurement.

The information respecting eastern Jefferson is indefinite, as the exposures seem to be very poor. Coal beds were seen in the east-central part of the county at 85 and 105 feet above the Upper Freeport, while on the Indiana border at the south are beds at 135, 310, and 385 feet, the last one 15 feet below an argillaceous limestone, 403 feet above the Upper Freeport. Two beds of red shale, 2 and 6 feet respectively, are at 185 and 222 feet, but the whole column is without notable sandstone except at the bottom, where the "Mahoning" is a massive rock. This

* I. C. White: Geology of West Virginia, vol. ii, pp. 233, 269, 310.

† C. A. Ashburner: (R R), pp. 209, 227.

Mahoning, from 50 to 70 feet thick, varies somewhat abruptly from massive and coarse, even pebbly, to shaly. Limestones are reported at 70, 90, and other distances above the Upper Freeport, but for the most part the intervals as given are merely estimates and the matter is indeterminate throughout. The Gallitzin coal bed seems to be present in Gaskill township, on the Indiana border, where it rests on the "Mahoning," and the coal bed in Young township, the next west, at 138 feet, may be the Brush Creek.*

The section is still obscure in northern Indiana west from Chestnut ridge. In the central part of the county, 12 miles south from the Jefferson line, Mr Platt finds coal beds at 40, 95, 147, and 177 feet above the Upper Freeport. That at 147 is not far from the place of the Brush Creek, for the lower coals are clearly the Gallitzin beds, as they are accompanied by the Upper and Lower Mahoning limestones, the Upper being represented by calcareous ore, which Mr Platt correlates with the "Johnstown ore" of Cambria county. The "Mahoning" of Jefferson is evidently the Lower Mahoning. Farther southwest, between Blairsville and Chestnut ridge, the whole of the Conemaugh is present. The Pittsburg limestone and shale, beginning at 20 feet below the coal, are 7 feet thick. A Little Pittsburg coal with its limestone persists at 45 feet, while at 125 feet is a coal and limestone exposure which may be at the Little Clarksburg horizon. Mr Platt finds a massive sandstone, 40 feet thick, beginning at 145 feet, which he takes to be the Morgantown; but it is extremely variable, for 2 miles away the interval is occupied by shales containing two red bands 5 and 3 feet, another bed of 7 feet being found at 210. The place of the Ames limestone is concealed in most of the sections reported, but that bed was seen, 3 feet thick, at 9 miles north from Blairsville, where it overlies the thick "Pittsburg reds" and is by barometer 280 feet above the Upper Freeport. The Brush Creek (Black Fossiliferous) limestone was not seen by Mr Platt and in all probability it is wanting, as the Mahoning is very thick in this corner of the county. If present it should be at about 130 feet below the Ames. The thickness of the Conemaugh as determined from exposures by Mr Platt is approximately 600 feet, but Mr Richardson gives it as 675 feet in the deep boring at Blairsville.† Mr Platt thinks the Mahoning at least 150 feet thick east from Blairsville, where an exposure shows Upper Mahoning massive, somewhat pebbly, and 50 feet thick. The Gallitzin (Philson) coal bed is in three benches and, including 8 feet of

* W. G. Platt: (H 6), pp. 21-23, 35, 73-74, 124.
† G. B. Richardson: U. S. Geol. Survey folios, Indiana (102), 1904.

clay partings, is 11 feet 9 inches thick, with the Mahoning limestone 5 feet thick and 2 feet 6 inches below it. The Lower Mahoning is said to be at least 75 feet thick.

Westward from Blairsville the rocks come up along the Kiskiminitas river (formed by union of the Conemaugh and Loyalhanna) and the lower beds are reached toward the western border of the county, near Salzburg, where the section is:

	Feet
1. Red shale	
2. Sandstone [Buffalo]	100
3. Sandy shale [black]	10
4. Sandstone [Upper Mahoning]	50
5. Coal bed [Upper Gallitzin]	Trace
6. Variegated shale	15
7. Sandstone	15
8. Coal bed [Lower Gallitzin]	Trace
9. Ferruginous limestone and ore [Mahoning]	
10. Shale	10
11. Sandstone [Lower Mahoning]	20
12. Slates	8

to the Upper Freeport, giving 124 feet as the thickness of the Mahoning, which is no longer wholly a massive sandstone as east from Blairsville. Stevenson states that the shales Number 3 are dark and argillaceous, carrying nodular ore which farther up the river becomes a continuous layer; so that here one finds the Brush Creek limestone.* The sandstone Number 2 includes not only the Buffalo, which is between the Cambridge and Brush Creek limestone, but also the Cowrun of Ohio, and the red shale is evidently near the Barton horizon. This sandstone becomes less prominent northward and at 12 miles from Salzburg the Brush Creek limestone was seen. That limestone was observed also farther north on the Armstrong border, where Mr Platt's section shows coal streaks at 58, 73, 100, and 117 feet below, with a limestone, 4 feet, underlying that at 73. The Upper Freeport is at only a few feet lower.† The limestone is representative of the Mahoning and the four coal streaks may be taken as illustrations of irregularities in subsidence and deposition at the Gallitzin horizon.

Armstrong county, west from Indiana, south from Clarion, and north from Westmoreland, is divided by the Allegheny river. East from that stream the Conemaugh is for the most part the surface formation and the Pittsburg coal bed is reached in the southeast corner.

* J. J. Stevenson: (K 2), p. 318.
† W. G. Platt: (H 4), pp. 157, 170, 174, 244, 257, 270, 280, 284.

Entering at the southeast, one finds the lower part of the section as at Salzburg, but at 5 miles from the county line, near Apollo, the Brush Creek (Black Fossiliferous) limestone is present at 134 feet above the Upper Freeport and 76 feet above the Lower Gallitzin, which is accompanied by the Mahoning limestone as at Salzburg. Already the great sandstone mass overlying the Brush Creek limestone has broken up and the Cambridge limestone, at 40 feet above the Brush Creek, is greenish gray, fossiliferous, and in many features much like the Ames, as at many localities in Ohio. The Ames (Green Fossiliferous) is given in the generalized section as about 215 feet below the Pittsburg coal bed and as resting on the Harlem coal. It is 24 feet below the Morgantown sandstone, which is 34 feet thick. The Pittsburg limestones are at 21 and 43 feet, but no trace of the Little Pittsburg and Clarksburg coals appears. The highest red shales are between the Morgantown and the Ames.

Northward from the Kiskiminitas the section is traced with ease along the east side of the county, where the great sandstones prevail for several miles. The Brush Creek coal bed is at 140 feet above the Upper Freeport, underlying the Buffalo-Cowrun sandstone, on which rest 8 feet of red shale. The Barton coal is shown in many places at about 75 feet below the Ames limestone, or 225 feet above the Upper Freeport, and the Gallitzin is represented by one or the other of its splits at several localities. On the west side of the Allegheny river the Ames is at 260 to 270 feet above the Upper Freeport and the Pittsburg reds are conspicuous as at several localities east from the river.*

Butler county is west from Armstrong and north from Allegheny. In the northern half one rarely finds more than 100 feet of Conemaugh. The Gallitzin (Millerstown of Chance) is at 35 to 55 feet above the Upper Freeport and occasionally becomes thick, 5 feet 10 inches at one locality, but the coal is inferior. Both divisions of the Mahoning are present and vary from massive to shaly sandstone.†

Entering southern Butler at the southeast, one has Doctor White's section showing two massive conglomerates, each 60 to 70 feet thick, separated by sandy shales, giving in all 160 to 170 feet. The Upper, or Buffalo, is the coarser, the pebbles being as large as hickory nuts, and its bottom at the type locality is 120 feet above the Upper Freeport. There the interval between it and the other plate, the Lower Mahoning, is concealed, but Doctor White's section on the Armstrong County border shows the conditions:

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* **W. G. Platt: (H 5), pp. 5, 21, 36, 68, 90-91, 163, 280, 288.**

† **H. M. Chance: (V), pp. 56, 90.**

	Feet
1. Ames limestone	3
2. Red shale	30
3. Gray shale	100
4. Coal bed [Anderson]	1
5. Limestone [Cambridge]	1
6. Concealed	10
7. Buffalo sandstone	50
8. Sandy shale	35
9. Gallitzin coal bed [Upper]	Trace
10. Sandy shale	35
11. Lower Mahoning sandstone	55

giving 317 feet from the Ames limestone to the Upper Freeport coal bed. The Buffalo sandstone is easily followed in all but the western townships of southern Butler; in those it evidently loses its conglomerate character and becomes less important. The Lower Mahoning, very coarse at the east and southeast, becomes shaly westward, while decreasing somewhat in thickness. The Gallitzin horizon is represented by thin coals at numerous localities, there being at least one bed wherever the interval is exposed. The highest is that in the Freeport section; elsewhere the highest is at 70 feet. In Forward township three beds are present at 20, 25, and 63 feet above the Upper Freeport, and two are shown at 35 and 60 in Jackson. The Mahoning limestone appears to be wanting throughout.

The Brush Creek coal and limestone seem to be almost wholly unrepresented in the eastern townships. The horizon is recognizable at many places as black, sometimes coaly, shale underlying the Buffalo sandstone, but the coal as such is distinct first in the western third. A Forward Township section shows 6 inches of coal separated by 10 feet of black shale from the overlying Buffalo; it is 115 feet above the Upper Freeport and 52 feet above the Upper Gallitzin. In Connoquenessing it is scattered through the black shale at 119 feet above the Upper Freeport and is 72 feet above a Gallitzin coal. In the southwest corner of the corner both coal and limestone are well shown, the type locality being on Brush creek, in Cranberry township.

The Cambridge (Pine Creek) limestone, shown in the Freeport section, is absent at all other localities where its horizon is reached. It is not noted in any of Doctor White's numerous sections, but the Anderson coal bed belonging above it is persistent at 5 to 20 feet above the Buffalo sandstone. The Barton (Bakerstown) coal bed is present in some of the townships along the Allegheny County border at 80 to 85 feet below the Ames limestone, but it is no longer an important member of the forma-

tion. The Cowrun sandstone, between it and the Cambridge limestone, is represented by shale in Butler county, though it is a well marked sandstone in Allegheny county. The Ames limestone is always seen where its horizon is exposed, as are also its underlying red shales, but the Harlem coal bed seems to be wholly wanting. The Elk Lick coal bed was seen in the only townships in which its horizon is reached.*

In southeastern Lawrence, west from Butler, a double coal bed is apparently persistent at 55 to 65 feet above the Upper Freeport limestone and overlying a fireclay containing much calcareous iron ore which at one locality is limestone, representing the Mahoning. In one place it is overlain by 20 feet of shale, but in another by a massive conglomerate.†

Beaver county, extending to the Ohio line, is south from Lawrence and west from Butler and Allegheny. Extensive erosion by large streams has removed the Conemaugh from much of the county north from the Ohio river, so that in the central portion that formation occurs in somewhat widely separated areas. The Elk Lick horizon is reached in a few places and the coal bed is shown. The Ames limestone and the Pittsburg reds are persistent, but the Harlem, Barton, and Anderson coal beds are apparently absent throughout. The place of the Cambridge limestone is rarely exposed, but that bed is present on both sides of the county at about 120 feet below the Ames and 60 to 65 feet above the Brush Creek. The Buffalo sandstone varies from coarse to fine sandstone or sandy shale and at one locality it is replaced by variegated shale.

In the northern tier of townships one finds at 6 miles southwest from the Lawrence County exposures, already referred to, a coal bed, evidently the Brush Creek, at 80 to 90 feet above the Upper Freeport and 12 feet below the decomposed Brush Creek limestone. Like that in Lawrence, this is a double bed, the upper portion more or less resembling cannel. The interval in Lawrence is 55 to 65 feet. Farther west a coal blossom appears on the hilltops at 58 to 70 feet above the Upper Freeport, with at 3 to 4 feet below it a slabby limestone, while still farther west, near the Ohio line, the interval is 60 to 65 feet. Four miles west, in Columbiana county of Ohio, Doctor White finds a coal at 50 feet, the interval being, as in northwest Beaver, concealed. This is the Coal 7, or the Groff vein, of northeast Ohio. Farther south in Beaver county one finds on the east or Butler County side the Brush Creek coal bed, 12 feet below its limestone, 185 to 207 feet below the Ames limestone and about 90 feet above the Upper Freeport, with a thin Gallitzin bed at

* I. C. White: (Q), pp. 24, 73-74, 76, 79, 80, 84, 87, 89, 91, 96, 99, 101-103, 106, 115, 123, 128-129, 135-136.

† I. C. White: (Q 2), pp. 76, 79, 80, 81, 82.

40 feet. At the next exposure, 7 or 8 miles west, the limestone already referred to is at 50 to 70 feet above the Upper Freeport, but no coal appears above it. Still farther west the coal is shown on the hilltops at 65 feet, while at 5 miles beyond, in Columbiana county of Ohio, Doctor White finds the interval 55 feet, with the massive conglomerate Buffalo sandstone resting on it.

Going southward along the Ohio line, one has this section at the Ohio river:

	Feet
1. Sandy shale	20
2. Pine Creek [Cambridge limestone]	2
3. Buffalo sandstone and sandy shale	65
4. Brush Creek limestone	1
5. Brush Creek coal and concealed	5
6. Mahoning sandstone, massive	80

to the Upper Freeport coal bed. At 3 miles east the massive Buffalo sandstone rests directly on the Brush Creek coal, which is 95 feet above the Upper Freeport. There seems to be no escape from the conclusion that the coal bed, 55 to 65 feet above the Upper Freeport in Lawrence and 99 to 65 feet in Beaver, is the same bed and at the Brush Creek horizon. If the limestone seen in central Beaver be the Mahoning of the eastern counties, the Upper Mahoning interval disappears northward and westward, bringing the Brush Creek coal down to the place of the Gallitzin coal.

A new coal horizon appears in eastern Beaver at 30 to 40 feet above the Brush Creek coal, dividing the Buffalo sandstone. Its place is exposed at only one locality.*

Southward from the area thus far described the Monongahela soon becomes the surface formation, and, except where anticlines are cut by streams, one finds only the upper portion of the Conemaugh exposed and the records of oil borings are the chief source of information. The thickness of the Conemaugh at the north is about 600 feet, but it decreases southward to about 560 feet at the West Virginia line.

South from the Kiskiminitas and east from the Monongahela river are eastern Allegheny, Westmoreland, and Fayette counties, the last extending to the West Virginia line. The Little Pittsburg coal beds, approximately 20 and 60 feet below the Pittsburg, are fairly persistent, though never economically important. Three limestones, 0 to 13, 45, and 60 feet below the Pittsburg, are shown at many places, though one rarely finds them all in a single section. The Clarksburg limestone

* I. C. White: (Q), pp. 179, 180-181, 183, 187-189, 208, 213-214, 223, 226, 235, 240, 245, 257, 260, 263; (Q 2), pp. 276, 282.

and its overlying coal bed or black shale are reasonably persistent. The Connellsville sandstone is usually somewhat massive, though at many places it becomes shaly or even is replaced by a more or less clayey shale, while the Morgantown is a characteristic sandstone not far from 50 feet thick. At a few feet below the last is the Elk Lick coal bed (Barton of Lesley and Stevenson) and the Ames limestone, 280 to 300 feet below the Pittsburg, appears almost invariably wherever its place is exposed, but the Harlem coal bed is reported from only one locality in Allegheny and one in Fayette. The Barton (Bakerstown) coal bed is apparently constant in Fayette county at about 75 feet below the Ames, but does not appear in sections within the other counties. The Cambridge limestone does not appear in any of Stevenson's sections, and the Buffalo-Cowrun sandstone, so conspicuous on the Kiskiminitas, disappears rapidly southward, where one finds only shales in its place above the Brush Creek (Black Fossiliferous) limestone, which rests on the Brush Creek coal bed. The Mahoning varies from massive sandstone to mere shale, and the Gallitzin coals, so persistent at the north, seem to be absent from southern Westmoreland and from Fayette. The red beds, except that underlying the Ames limestone, become insignificant and are practically unrepresented in Fayette.*

The records of oil borings in these counties west from the narrow strip of exposed Conemaugh for the most part give little detail or are not referable to any fixed datum. A record in northwestern Westmoreland shows the Buffalo sandstone 70 feet thick and beginning at 110 feet below the Pittsburg reds. The Mahoning, beginning 20 feet below the Buffalo, is double and rests on the Upper Freeport at 595 feet below the Pittsburg. The Pittsburg red is the lowest red bed, but a record near Irwin, on the Pennsylvania railroad, shows three reds, 20, 32, and 5 feet thick respectively, at 395, 459, and 546 feet below the Pittsburg coal bed. The upper Freeport is reached at 605 feet and only shales are present to 280 feet above it. A record in central Fayette county gives a thickness of 590 feet for the Conemaugh and red shale is absent.†

Northern Allegheny, south from Butler, is between the Allegheny and Ohio rivers. The exposed section extends from the Upper Freeport at the north to the Pittsburg at the south. The Ames limestone is shown in every township at from 280 to 300 feet below the Pittsburg coal bed and the Elk Lick coal, at 25 to 35 feet above the Ames, occasionally overlies a black fossiliferous limestone which may be the equivalent of the

* J. J. Stevenson: (K K), pp. 64, 74, 75, 137, 141, 171, 172, 182, 274, 316, 318, 348.
† J. F. Carll: Oil and Gas Report for 1889, pp. 214, 221, 226, 320-322.
I. C. White: Geology of West Virginia, vol. *ia*, p. 115.

Somerset Elk Lick limestone. The Harlem coal appears in many sections, but is distinctly absent from others. The Pittsburg reds are a striking feature wherever their horizon is reached, and the Bakerstown (Barton) coal bed, 75 to 80 feet below the Ames, occasionally attains workable thickness. Between it and the Cambridge limestone there is sandstone or sandy shale 40 feet thick, the Cowrun of Ohio. The Anderson coal is wanting and the sandstone rests on the limestone. The interval between the Cambridge and Brush Creek limestones, ordinarily about 60 feet, is sometimes filled by the Buffalo sandstone. In one of the southern townships the Salzburg condition is repeated and the Buffalo is continuous with the Cowrun, giving a continuous sandstone about 100 feet thick. Toward the Beaver County line the Buffalo becomes less conspicuous and at times is replaced in great part by shale. The sandstone sometimes cuts out the underlying Brush Creek limestone, which here has all its characteristic features, and is separated by a few feet of black shale from the Brush Creek coal bed, which is from 60 to 100 feet above the Upper Freeport. The variation in this interval is due chiefly to changes in the Lower Mahoning, which at times almost disappears. At one locality the Upper Gallitzin is at 45 feet and the Mahoning limestone at 10 to 15 feet above the Upper Freeport.

Above the Ames there are few persistent beds. The Morgantown sandstone is constant, often forming cliffs; a red bed 20 feet thick begins at 90 feet above the Ames and is present in many sections. The Pittsburg limestones are irregular.*

West from the Monongahela and south from the Ohio are western Allegheny, Washington, and Greene, the last extending to the West Virginia line at the south. The surface formation is the Monongahela and except along the Monongahela river and along the northern border of the area the Conemaugh is deeply buried. The exposed section at the north extends but a little way below the Ames limestone.

In western Allegheny two limestones within 30 feet below the Pittsburg coal bed are commonly found; they are more or less brecciated in structure and in most localities contain minute fossils, which are supposed to be of fresh-water types. Another at 140 to 150 feet may be at the Little Clarksburg horizon. Red shale beds were seen at 65, 89, 106, 175, and 194 feet, but not all of them in any one section; that seen at 106 is evidently the lower portion of a 50-foot bed observed elsewhere at 89 feet; that at 194 feet is apparently equivalent to one seen in northern Allegheny at 90 feet above the Ames. Within short distances the

* I. C. White: (Q), pp. 149, 154, 158, 159, 160-165, 171-178.

whole section changes and neither limestone nor red shale appears. The Ames limestone, 280 to 300 feet below the Pittsburg, is constant and at many places is accompanied by the Harlem coal bed. In the Painter well, on the Monongahela river above Pittsburg, the Cambridge limestone is at about 420 feet below the Pittsburg and a coal, probably the Gallitzin, is at 528. The Mahoning is represented by shale.*

In Washington county one finds at the extreme north the Elk Lick coal bed, 10 feet below the 90-foot Morgantown sandstone or 260 feet below the Pittsburg and 35 feet above the Ames limestone, which rests on the Harlem coal. The Little Pittsburg coals are wanting, but there are two persistent limestones within 30 feet. On the Monongahela 3 limestones occur in this interval and the Little Pittsburg coal is represented by black shale.

The records of oil borings show irregularity in the Conemaugh section. The interval from the Pittsburg coal bed to the Mahoning varies from 463 to 488 feet, that rock in some cases being almost continuous above with the Buffalo. Both divisions of the Mahoning are distinct and are usually sandstone, though varying greatly in thickness; occasionally, however, one or the other is replaced by shales, and changes of this kind are frequently abrupt. One of two wells near the borough of Washington shows the Upper Mahoning all sandstone, but in the other it is all shale.

The Buffalo sandstone is represented by shale at McDonald; at other localities it is distinct as a sandstone, but very variable. In one well at Washington it begins at 413 feet, evidently replacing the Cambridge limestone, and is separated by but 4 feet of shale from the Mahoning at 488, thus giving an almost continuous mass of sandstone, 107 feet thick; but in the other well it begins at 428, is only 20 feet thick, and is separated by 100 feet of "slate and shells" from the Lower Mahoning. At Beallsville, east from Washington, it begins at 448 and is 25 feet thick. The sandstones above the Buffalo are equally irregular; the Morgantown horizon is sufficiently well marked, but the other beds, some of them very thick, can not be correlated with any at exposed sections. No coal is recorded anywhere except at McDonald, where the Little Clarksburg is at 175 and a Gallitzin bed at 501 feet below the Pittsburg.

The red beds are important members of the formation, though they are extremely variable. There are three horizons, 129 to 174, 236 to 310, and 367 to 413, within which these beds occur in almost all of the

* J. J. Stevenson: (K), pp. 296, 298, 324-326, 306-309, 310, 314.
I. C. White: Geology of West Virginia, vol. *ia*, pp. 101-102.

wells, the whole interval in some cases being filled with red shale. Thin beds are found in different wells at 528 and 567 feet.*

In Greene county the upper 250 feet of the Conemaugh are shown on the Monongahela river. Impure limestone is at 4 feet below the Pittsburg coal, and a little Pittsburg coal bed is at 40 feet overlying a limestone. The Clarksburg limestone and its overlying coal bed are at 130 to 140 feet, and the Morgantown sandstone, 95 feet thick, is well shown overlying the Elk Lick coal bed, which is 2 feet 4 inches thick and 245 feet below the Pittsburg. A fossiliferous shale with many lamellibranchs was seen near Greensboro at 148 feet.

Records of oil borings in the interior of the county are available for the north border, the center, and the southern border near the West Virginia line. No coal is noted in any boring except at the south, where the Barton is at 350 feet below the Pittsburg. The thickness of the Conemaugh in that part of the county is 560 to 565 feet. The Connellsville sandstone is present in the north and center, with its base at 120 and 128 feet below the Pittsburg; the bottom of the Morgantown is from 226 to 235; the Buffalo horizon is marked in the north and center by a mass beginning at 390 and 401 feet, and in the north it is 90 feet thick. The Upper Mahoning is present in two records, beginning at 481 and 451 and ending at 511 and 486. It is wanting in the west central part of the county, where only shales are recorded to 140 feet below the Buffalo sandstone. The Lower Mahoning is present in all records except that of the west central region, the bottom being at 591, 560, and 565, in the last resting directly on the Upper Freeport. The intervals within which the red beds appear are 120 to 183, 205 to 290, and 385 to 415, answering to those of Washington county; each of these is almost filled with red shale in one or other of the wells. A lower horizon is at 500 to 510. The greatest thickness in all of red shale is in the central part of the county, where 135 feet is found in the first and second intervals, there being none in the third; the least is near the Monongahela, where a single bed, 5 feet thick, is reported at 351 feet.†

THE NORTHERN PANHANDLE OF WEST VIRGINIA

It is well to carry the section to the Ohio river across the narrow strip in West Virginia adjoining at the east southern Beaver, Washington, and Greene counties of Pennsylvania.

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* J. J. Stevenson: (K), pp. 178, 207, 271, 279, 280, 283.
J. F. Carll: Ann. Rept. for 1886, pp. 762, 764.
I. C. White: Geology of West Virginia, vol. *ia*, pp. 112, 113, 117, 118.

† J. J. Stevenson: (K), pp. 90-91, 94, 115-116.
J. F. Carll: Oil Rept. for 1889 (15), pp. 31, 35.
I. C. White: Geology of West Virginia, vol. *ia*, pp. 122-123, 130.

The most northerly patch of the Pittsburg coal in West Virginia is in Brooke county, a few miles north from Steubenville, though in Jefferson county of Ohio a similar patch is found nearly 10 miles farther north. Doctor White's measurements in the Kings Creek region of that county give a somewhat greater thickness to the Conemaugh than do those on the Ohio side, the interval to the Steubenville shaft coal bed, the Lower Freeport, being 580 feet and to the Upper Freeport 515 feet. Professor Newberry's measurement on Wills creek, in Ohio, are 493 and 558 feet; but the intervals vary here with great abruptness. The Morgantown sandstone, Elk Lick and Anderson coal beds are exposed, the last underlying the massive Cowrun sandstone 40 feet thick. The Ames, Cambridge, and Brush Creek limestones are present, the last two being 70 feet apart. The Brush Creek limestone and black shale rest on the Brush Creek coal bed, under which is calcareous shale representing the Mahoning limestone. The Lower Mahoning is represented by massive sandstone resting on the Upper Freeport, which is 50 feet below the Brush Creek. Red shales are shown above the Morgantown sandstone as well as under the Ames and Cambridge limestones, but the beds are thin.

Nine miles farther south the Upper Freeport is absent, and the interval from Ames limestone to Lower Freeport coal bed is 324 feet. On the Ohio side of the river the distance from Pittsburg to Lower Freeport is 556 feet, making the Ames about 225 feet. At Wheeling the interval between the two coals is 556 feet, with the Anderson coal bed at 355 and only "variegated shale" for 280 feet above that bed; but at 3 miles southeast from Wheeling a sandstone, 150 feet thick, begins at 136 feet below the Pittsburg, and a coal bed is reached at 395 feet which is too high for the Brush Creek, but is very near the place of a bed seen in northern Beaver and seen frequently in Jefferson county of Ohio. Two red beds 20 and 25 feet are in the interval between the sandstone and this coal bed. The Mahoning interval is filled with shale and the first sandstone is in the Allegheny at 545 feet. Three miles south from Wheeling there is little aside from shale between the Pittsburg and a coal bed at 530 feet which rests on a great sandstone continuing to the bottom of the Carboniferous. Red shale begins at 50 feet below the Pittsburg and thence it predominates. It is altogether probable that the coal bed at 530 feet is the Upper Freeport, as the intervals increase slightly southward.

At 12 miles southeast from Wheeling, in Marshall county and on the Pennsylvania border, 12 miles west from the boring in northern Greene county, a record shows coal beds at 333 and 593 feet below the Pittsburg; the latter is the Lower Freeport, but the former is too high for the

Anderson, which is due at about 370. It may be at the Barton horizon, which is marked by coal at a number of places in Jefferson county of Ohio. The Mahoning, almost wholly sandstone, begins at 478 and continues into the Allegheny at 558 feet. Six thin red beds, in all only 45 feet, are recorded, the lowest being at 378 feet. Near Moundsville, on the Ohio river, 10 miles south from Wheeling, a sandstone 85 feet thick begins at 197 feet below the Pittsburg and ends at 282, very nearly as at 3 miles southeast from Wheeling. It rests on 70 feet of red shale, separating it from a sandstone 60 feet resting on coal at 437 feet, which is near the Brush Creek horizon. In southern Marshall the well records note only the sandstones. The Mahoning, as a sandstone, begins at 450 to 480 feet and ends at 526 to 532, where it can be differentiated from the Allegheny beds. The Lower Freeport, in Wetzel county south from Marshall, is at 575 feet below the Pittsburg. In the wells of southern Marshall, as in those of northern Wetzel, a sandstone, the Cowrun (Salzburg of the records) begins at about 300 feet below the Pittsburg.*

OHIO

Passing over into Ohio, one finds the most northerly exposures in Columbiana county adjoining Beaver of Pennsylvania. At Palestine, in the northern part of the county, the Brush Creek coal is at 50 feet above the Upper Freeport and the Mahoning limestone is absent. At other localities, according to Professor Newberry, the interval is 60 feet. This is Coal 7 of the northern Ohio series, known locally as the "Groff vein." Farther south, toward the border of Jefferson county, numerous sections measured by Professor Newberry show the interval from 58 to 52 feet, with the Mahoning limestone at 3 to 8 feet below the Brush Creek coal. The Lower Mahoning is "sandstone and shale" 20 to 40 feet thick. A limestone, 10 feet thick, including shale, appears in some of the sections at 0 to 20 feet above the Brush Creek coal. This, cut out in many places by the overlying sandstone, is black, nodular, contains many fossils, and is the Brush Creek limestone of Pennsylvania. The Buffalo sandstone is irregular in southern Columbiana, at times very coarse, as near Wellsville, but for the most part rather fine grained and often mere shale. Sections along the Columbiana-Jefferson border reach in several instances to the Ames limestone, which overlies the Pittsburg reds, 50 feet thick, and is 225 to 255 feet above the Brush Creek coal bed. At Irondale the interval between Ames and Brush Creek is occupied wholly by red and

* I. C. White: Geology of West Virginia, vol. i, pp. 363, 366-367; vol. ia, pp. 214, 217, 226, 231; vol. ii, p. 241.

olive shale. A thin coal bed rests on the Ames limestone at this place, but elsewhere it is 20 feet above, with green and red shale between them. It appears to be at the Elk Lick horizon. Nearer the Ohio river the Harlem coal is immediately under the Ames, the Barton is at 50 to 60 feet below, and the Lower Mahoning is coarse and pebbly sandstone. The interval between the Brush Creek and Upper Freeport varies from 35 to 69 feet between Irondale and the Ohio river, and the Mahoning limestone (Gray limestone of Newberry) is present in most of the sections.*

Southward in Jefferson county numerous direct measurements by Newberry, Orton, and Newton show that the interval from the Ames limestone to the Brush Creek coal varies within 16 miles from 199 to 230 feet, the least interval being at Steubenville, the most southerly measurement. This interval is filled mostly by red and olive shale, but at several localities a coal bed appears at 27 to 46 feet above the Brush Creek, marking a horizon first seen in eastern Beaver of Pennsylvania. The interval from Brush Creek to Upper Freeport varies along this line from 37 to 85 feet. At 3 miles southeast from the northwest corner of the county Professor Newberry found the Harlem coal immediately under the Ames limestone and another coal bed at 114 feet lower, immediately above an impure limestone, the Cambridge, at 118 feet. This, the Anderson coal bed, underlies variegated shale, but 10 miles away toward the southeast, in Brooke county of West Virginia, it is 100 feet below the Ames and underlies the massive Cowrun sandstone, 40 feet thick. A bed at the Barton horizon is noted at several localities 55 to 65 feet below the Ames limestone.

The interval from the Pittsburg coal bed to the Ames limestone varies from 149 feet in northern Jefferson to 225 feet in the southern part of the county. A limestone is usually seen at 1 to 25 feet below the Pittsburg; a coal and limestone marking the Little Clarksburg horizon are exposed occasionally in northern Jefferson, and at one locality cannel occurs at a Little Pittsburg horizon 40 to 50 feet below the coal. The Elk Lick horizon is marked by coal at many places 20 to 35 feet above the Ames; but the section shows much variation, the whole interval being occupied at one place by blue and sandy shales to 180 feet above the Ames. Red beds are at several horizons, but, excepting those associated with the Ames, they are thin and of uncertain occurrence. The interval from Pittsburg to Upper Freeport is 498 feet in northern Jefferson, 493 at

* This is the Brush Creek limestone of volume v.

Wills creek, and about 515 feet at Steubenville as well as at 10 miles farther south.*

Carroll county is west from Jefferson. The careful work of the Third Ohio Survey superseded the reconnaissance made by Stevenson in 1872 and resolved the difficulties that so perplexed that observer. Two sections by Professor Orton suffice to show the variations. Midway in the county the Brush Creek coal bed at 130 feet below the Ames limestone is 45 feet above the Upper Freeport, but at 10 miles farther south the intervals are 195 and 71 feet, both sections showing the Mahoning and Cambridge limestones, the latter at 120 feet below the Ames. In both sections the Lower Mahoning is shale, the Upper Mahoning, as apparently at all localities in Ohio, being absent. The Pittsburg reds, so conspicuous farther east, are wanting and the only red bed in the section is 20 feet thick, at 70 feet above the Ames and underlying a limestone whose top, at 115 feet, can not be more than 40 feet below the Pittsburg coal. According to Stevenson, the Ames limestone is double midway in the county, where the Harlem coal bed occasionally attains workable thickness, especially near the village of Harlem. A coal horizon, evidently the Anderson, is distinct at 75 to 105 feet below the Ames limestone, the interval increasing southward.†

The whole of the Conemaugh is exposed in Harrison county, south from Carroll and west from Jefferson. The Ames limestone is rarely more than 150 feet below the Pittsburg coal bed. Even in the southeast corner of the county the interval is but 149 feet, though at 6 miles eastward, in Jefferson, it is 225. The Harlem coal bed is shown at many places and occasionally attains workable thickness. The Anderson coal is distinct at 90 to 104 feet below the Ames, as is the Brush Creek at 42 feet above the Upper Freeport. The Elk Lick coal was seen frequently as coal or coaly shale at 8 to 12 feet above the Ames limestone. Neither the Cambridge nor the Mahoning limestone is noted in any of the sections. Limestone is persistent almost directly below the Pittsburg coal, but aside from that none of the beds above the Ames is persistent.‡

Belmont county, south from Harrison and Jefferson, extends to the Ohio river. On the river side the exposed section reaches downward to

* J. S. Newberry: Ohio, vol. iii, pp. 96, 99, 107, 731-732, 736, 739, 740, 746, 750, 751, 753.
J. S. Newberry and Henry Newton: Vol. ii, sections, sheets nos. 1, 2.
J. J. Stevenson: Vol. iii, pp. 765, 768, 771, 773, 778.
E. Orton: Vol. v, pp. 50-51, 53-54, 61.
I. C. White: Pennsylvania (Q Q), p. 282.

† J. J. Stevenson: Vol. iii, pp. 180, 182-183.
E. Orton: Vol. v, p. 255.

‡ J. J. Stevenson: Vol. iii, pp. 205-206, 208.

little more than 100 feet below the Pittsburg, and the rocks, aside from a limestone at 1 to 17 feet, are almost wholly sandstone. The record of an oil boring in Washington township 6 or 8 miles from the river shows only shales for 750 feet below the Pittsburg coal, resting on the Pottsville, a sandstone 258 feet thick. Red beds 25 and 155 feet thick begin at 30 and 95 feet below the coal. This is not more than 2 miles from Moundsville, in West Virginia, where a massive sandstone 85 feet thick begins at 197 feet below the Pittsburg and is separated by 70 feet of red shale from a lower bed of sandstone 60 feet thick. In the western part of the county the section reaches to the Ames limestone, which is barely 140 feet below the Pittsburg. Limestone 4 to 30 feet thick is at 0 to 12 feet below the Pittsburg, but thence to the Ames one finds in the northwest part of the county little aside from sandstone, while in the southwest part much of the interval is filled with shale.*

Some small outliers of Conemaugh remain in Tuscarawas county west from Carroll and Harrison, where Professor Newberry found the Brush Creek (*7a*) at 53 feet above the Upper Freeport (*7*). The Lower Mahoning, 30 feet thick, is the Stillwater conglomerate of Newberry and underlies 10 feet of red shale. Overlying the Brush Creek are 60 feet of mostly olive shale, replacing the Buffalo sandstone.†

Guernsey county, south from Tuscarawas and west from Belmont, has the whole Conemaugh section exposed. In the northeastern part, near the Belmont line, the Ames limestone is 148 to 152 feet below the Pittsburg coal bed, with, in the interval, limestones at 12 and 68 feet, but no coal, very little sandstone, and no red shale. In the southeast portion the interval to the Ames varies from 138 to 160 feet, with limestones at 10, 27, and 53 feet, and a red bed 20 feet thick beginning at 54 feet. At one locality Professor Andrews found a fossiliferous limestone 1 foot thick 65 feet above the Ames, and at another probably the same bed at 80 feet below the Pittsburg. The Ames limestone persists throughout the county. A section in the central part of the county by Professor Orton is:

	Feet.	Inches
1. Limestone		
2. Concealed	68	0
3. Anderson coal bed	2	6
4. Red shale	10	0
5. Cambridge limestone	4	0
6. Fireclay and red shale	15	0

* E. B. Andrews: Vol. ii, p. 547.
J. J. Stevenson: Vol. iii, pp. 262-263.
J. A. Bownocker: Fourth Survey, Bull. no. 1, p. 220.

† J. S. Newberry: Vol. iii, p. 81.

	Feet.	Inches
7. Concealed	20	0
8. Sandstone, heavy [Buffalo]	25	0
9. Fossiliferous black shale [Brush Creek]......	5	0
10. Brush Creek or Groff coal bed	1	0
11. Concealed	25	0
12. Upper Freeport coal bed		

Red shale is not reported as associated with the Ames limestone in the northern part of the county, and it was seen at that horizon in the southern part only near the Belmont County line. The Harlem coal is reported from one locality in northern Guernsey, where, according to Stevenson, it is roofed by cannel which is "full of aviculoid shells." For the most part its place is concealed in sections by Andrews, but it is reported by him twice in the southern part of the county at 12 to 18 feet below the Ames.

The Anderson coal bed of Andrews, Norwich of Stevenson, is at most 86 feet below the Ames, 10 feet above the Cambridge limestone, and is persistent, having been seen in all parts of the county. The Cambridge limestone is present throughout the western townships at 86 to 96 feet below the Ames; it is below the surface in the eastern portion. The interval from it to the Upper Freeport (locally Cambridge of Andrews and Stevenson) varies from 91 to 137 feet, increasing toward the southern border. The Brush Creek fossiliferous shales have not been observed in the interval between western Jefferson and central Guernsey, being removed at most localities during deposition of the overlying Buffalo sandstone or sandy shale. The Brush Creek coal is worthless at all exposures in Carroll, Harrison, and Guernsey, and the Lower Mahoning is usually represented by shale. The average thickness of Conemaugh in this county is about 350 feet—a decrease of almost 250 feet from McDonald, in Washington county of Pennsylvania.*

In Muskingum county, west from Guernsey, the section north from the Baltimore and Ohio railroad reaches upward to the Ames limestone. The Harlem coal persists at 2 to 17 feet below that limestone and the Cambridge limestone was seen at 69 feet below the Ames. The Anderson coal at 1 to 9 feet above the Cambridge limestone is equally persistent with the Harlem, but for the most part both beds are mere streaks. The Cambridge limestone is fossiliferous, buff on weathered surface, and often flinty and is 127 feet above the Upper Freeport (Cambridge) coal. The Lower Mahoning, fully exposed at one place, consists of two sandstone plates, 20 and 7 feet, separated by 21 feet of mostly sandy shale.

* E. B. Andrews: Vol. ii, pp. 533-534, 535-539, 540-541.
J. J. Stevenson: Vol. iii, pp. 225-228.
E. Orton: Vol. v, pp. 82, 84, 87.

The section in southern Muskingum is complete and the following generalized succession may be compiled from measurements by Professor Andrews:

	Feet.	Inches
1. Pittsburg coal bed		
2. Interval	1 to 2	0
3. Limestone	1	0
4. Sandstone	27	0
5. Limestone	2	0
6. Red shale	25	0
7. Coal bed	Trace	
8. Shale	90	0
9. Ames limestone	1 to 2	0
10. Shale and sandstone	27	0
11. [Harlem] coal bed	0 to 2	6
12. Concealed and sandstone	44 to 48	0
13. Anderson coal bed	2	6
14. Clay and shale	10	0
15. Cambridge limestone	8 to 12	0
16. Clay and shale	50	0
17. Limestone [Brush Creek]	Thin	
18. Concealed	3	0
19. Brush Creek coal bed	Thin	
20. Clay	6	0
21. Lower Mahoning sandstone	40	0

to the Upper Freeport coal bed. Number 8 contains at some places 60 feet of red shale, the "Big Red" of counties farther south; the red bed, Number 6, is apparently the same with that seen in the eastern localities. No trace of the Elk Lick coal appears in any of the sections and the Harlem is very uncertain, but the Anderson is persistent at about 70 feet below the Ames, sometimes resting almost directly on the Cambridge limestone. The sandstone, Number 12, is at the place of the Cowrun. The Brush Creek coal and limestone are very thin and the former is reported very rarely.*

Morgan county is south from Muskingum. In the central and northern portion the Pittsburg coal bed is 142 to 150 feet above the Ames limestone. A thin limestone appears occasionally at a few feet below the Pittsburg and a 2-foot coal bed is at 73 feet, possibly the Jeffers of more southern localities. The Harlem coal bed is double in some places, the upper division directly under the Ames, and the lower, occasionally of workable thickness, at 20 or even 30 feet lower and resting on the Ewing limestone. Still lower is the Patriot coal of Lovejoy, about 40

* E. B. Andrews: Vol. i, pp. 314 et seq.
J. J. Stevenson: Vol. iii, pp. 284-289.

feet above the Cambridge limestone in Morgan county and overlying the Cowrun sandstone, an important rock in northwest Morgan, where it is the First oil sand of the Federal Creek and Buck Run districts. It is the 140-foot sand of the Macksburg area and the Cowrun of Washington county. An oil-well record given by Professor Bownocker in Union township shows an almost continuous red bed beginning at 33 feet above the Ames and extending upward to 156 feet, to the place of the Pittsburg, which is wanting. Only 6 feet of red shale are reported below the Ames, and that limestone is 131 feet above the Cambridge, which is only 70 feet above the Upper Freeport coal. It is worth noting that while the interval from Ames to Cambridge has increased, that from Ames to Upper Freeport is but 201 feet—only about 10 feet more than in southern Muskingum. The Cambridge is double in much of Morgan and at times both divisions are flinty, but in several townships only the upper division is present. The interval between the divisions varies from 5 to 10 feet and holds the Anderson coal bed.

Professor Bownocker reports several oil records from eastern Morgan. One at Browns Mill, near the southeast corner, shows the "Big Red" ending at 4 feet above the Ames limestone, and the Cowrun sandstone, 29 feet thick, beginning at 92 feet below it. A red bed at 184 feet above the Ames is very near the place of the Pittsburg coal. Seven miles west the "Big Red," 125 feet thick, ends at 22 feet above the Ames, and another, 16 feet, ends at 40 feet above the Cambridge limestone. These reds are very irregular, for in a well 4 miles farther west the only red between Ames and Cambridge is 42 feet and ends at 65 feet above the Cambridge, whereas in an adjacent well there are two beds 10 and 40 feet. In the most western well coal is recorded at 165 feet below the Ames, 58 feet below the Cambridge, evidently the Brush Creek, and black shale at 42 feet lower is very near the place of the Upper Freeport. The Conemaugh in eastern Morgan is not more than 360 feet thick.*

Noble county is east from Muskingum and Morgan, south from Guernsey. For the most part the Conemaugh is deeply buried, but it is brought up by an anticline midway in the county. According to Professor Andrews, the interval from Pittsburg to the Ames in the northwest portion is 150 feet. Farther east on the Guernsey border this interval contains two thin limestones at 46 and 54 feet above the Ames and another, very thin, at the Pittsburg horizon. The Cambridge limestone becomes double near the Guernsey line, a new, upper division making its appearance,

* E. B. Andrews: Vol. i, pp. 295-297, 303, 305.
E. Lovejoy: Vol. vi, pp. 631-635.
J. A. Bownocker: Bulletin no. 1, pp. 134, 136, 142.

which becomes the important bed in Morgan and other counties beyond toward the south. Here Professor Andrews found 6 inches of fossiliferous ore on 6 inches of fossiliferous shale resting on the Anderson coal bed, 1 foot 6 inches thick and 10 feet above the Cambridge limestone proper, also fossiliferous, which is 125 feet above the Upper Freeport (Cambridge) coal bed. Farther south he finds a fossiliferous limestone, below which, at 90 feet, is another fossiliferous limestone, dark blue and sandy, resting on a coal bed. Still farther south, and near the Washington County line, he finds the lower limestone resting on its coal bed. The higher limestone is the Ames and the lower, or main portion of the Cambridge, is about 100 feet below it. An oil record on the border of Washington county and 18 miles northeast from the Browns Mill well, in Morgan county, shows the Ames at 125 feet above the Cambridge with the 140-foot, or Cowrun, sandstone, 5 feet thick and 26 feet above the Cambridge. It overlies a thin coal bed separated from the limestone by red shale.*

Monroe county is east from Noble and extends to the Ohio river. The Conemaugh and even much of the Monongahela formation are deeply buried. The Pittsburg coal bed is insignificant and in a great part of the county it is wanting; the well records are of the ordinary type and the thinner limestones can not be recognized, but the "Big Lime" of the Lower Carboniferous is persistent. The Mahoning and other sandstones, so insignificant on the western outcrop, reappear in these records, and it is not altogether easy to correlate them with those in Noble and Morgan, as the "Big Lime" is not present in those counties. Professor Bownocker gives records of borings in Summit, Wayne, Perry, Jackson, and Green townships, and Doctor White adds one on the Ohio river opposite Sisterville, in Tyler county of West Virginia. These extend southeastward across the county, the first being about 6 miles west from the Noble County line. A thin coal bed is present in most of them and it is taken as the main horizon, the numbers indicating distance below it.

	Feet.	Feet.	Feet.	Feet.	Feet.	Feet
Coal bed [Pittsburg]						
Big Red:						
Top	153		105			
Bottom	253		245			
Cowrun sandstone:						
Top	453	507	520	470	534	430
Bottom	678	900	540	485	565	480
Coal bed [Brookville] ..	678		705			
"Big Lime"	1032		1060		1060	1050

* E. B. Andrews: Vol. ii, pp. 510, 511, 513, 515, 517, 518.
J. A. Bownocker: Bulletin no. 1, p. 160.

Where no numbers are given the well record is incomplete. In many cases the sandstones alone are recorded. The coal bed, sometimes wanting and always very thin, is the Pittsburg. It is evident that the "Cow-run" is not the same bed in all of these wells. At the Summit locality one is at little more than 12 miles northeast from the well in southern Noble, where both Ames and Cambridge limestones are present and the latter is about 300 feet below the Pittsburg. The interval from Pittsburg to the "Big Lime" in Monroe does not justify the supposition that there is any notable thickening of the measures in this direction. Evidently the sandstone beginning at 430 to 453 and ending at 480 to 485 is the Mahoning, which in the Summit well is continuous with the Allegheny and in the Wayne well is continuous through the Allegheny into the Pottsville. The Brookville coal bed at 678 and 705 feet will prove to be a useful guide in Washington county.*

The Hocking Valley coal field of Ohio embraces portions of Perry, Hocking, and Athens counties along the western outcrop. Professor Orton's generalized section for the lower portion of the Conemaugh in the western part of these counties is:

	Feet.	Inches
1. Ames limestone	5	0
2. Shale, red or drab	45	0
3. Ewing limestone	3	0
4. Shale, red or drab	40	0
5. Cambridge limestone, black, in 2 benches	10	0
6. Shale	25	0
7. Mahoning (?) [Buffalo] sandstone	20	0
8. Brush Creek coal	2	6
9. Shale	15	0
10. Brush Creek [Mahoning] limestone	0 to 3	6
11. Mahoning sandstone or shale	15 to 25	0

the Cambridge limestone being 98 feet below the Ames and about 80 feet above the Upper Freeport coal bed; but the variation is extreme in the outlying areas of Perry and Hocking. At one locality in the former, according to Professor Orton, the section begins with the Elk Lick coal at 16 feet above the Ames and reaches to the Upper Freeport, giving in all only 115 feet from Ames to Upper Freeport, all members of the section being present, thus making less than 275 for the whole of the Conemaugh; but another section farther east in the same county shows the Cambridge 94 feet 6 inches above the Upper Freeport and 52 feet above the Brush Creek coal bed. The section in Hocking county covers the

* J. A. Bownocker: Bulletin no. 1, pp. 201, 210, 212.
I. C. White: Geology of West Virginia, vol. i, p. 356.

whole of the Conemaugh. Mr Read found the Pittsburg coal bed 145 feet above the Ames limestone and the latter 112 feet above the Cambridge, which is only 72 feet above the Upper Freeport, giving thus a thickness of 329 feet for the Conemaugh. The Brush Creek coal bed and the Mahoning limestone are present in his sections, the latter being sometimes only an ore bed.*

Athens county is south from Perry and Morgan and east from Hocking. Professor Andrews finds the Ames limestone 138 to 145 feet below the Pittsburg (Federal Creek) coal and the Cambridge limestone at 85 to 90 feet lower, with, at some localities, the intermediate Ewing limestone at 50 feet above the Cambridge. The Ames is 180 to 190 feet above the Upper Freeport (Baileys run) coal bed, practically the same as in Read's Sunday Creek section in Morgan county, so that the Conemaugh in all is about 330 feet thick. Limestones, not wholly persistent, are 4 to 6 and 75 feet below the Pittsburg. The Harlem coal seems to be persistent at about 25 feet below the Ames and at times underlies a sandy black fossiliferous shale. The interval between Ames and Cambridge is fully exposed near Athens, midway in the county, where, aside from the Harlem coal and Ewing limestone, it contains only shale and laminated sandstone, 34 feet of the latter resting on the Cambridge limestone, the Cowrun sandstone. The Cambridge limestone is double in the northern part of the county and the interval between the divisions is at times more than 25 feet; but the lower division, underlying the Anderson coal bed, disappears midway in the county, to reappear irregularly farther south. In this region the upper division is persistent. Occasionally one or both are flinty, but the upper is sometimes pure enough to yield good lime. The interval between Ames and Pittsburg in the eastern township of Ames is 140 feet, according to Andrews, but Mr Lovejoy finds it 171 farther west, where the section shows great variation. A coal and limestone—perhaps the Jeffers—are sometimes present at 54 to 57 feet; a white limestone underlies the Pittsburg at one locality, but at another, one finds 28 feet of red shale; while at a third, heavy sandstone fills the whole interval to the Ames.

On the Morgan-Athens border the Ames is 170 feet below the Pittsburg, and in Ames township of the latter it is 115 feet above the Cambridge limestone, evidently the Upper Cambridge, for it underlies 33 feet of sandy shale, representing the Cowrun sandstone. Here, at 6 miles east from the line of Washington county, Professor Bownocker's measurements and oil-well records make the Cambridge limestone 285 feet below

* M. C. Read: Vol. iii, pp. 679, 705.
E. Orton: Vol. v, pp. 100-101, 920.

the Pittsburg. The "Big Red" rests on the Ames, but is only from 15 to 40 feet thick. Two other reds, 5 and 20 feet, are at 10 and 30 feet above the Cambridge, but are not present in all of the wells.*

Crossing into Washington county, east from Morgan and Athens, south from Noble, and extending to the Ohio river, one finds the Conemaugh for the most part deeply buried; but the Cowrun anticline brings it up in a narrow strip east from the middle line of the county.

A well record reported by Professor Bownocker from the northwestern part of the county shows the Cambridge limestone at 120 feet below the "Big Red," which is 95 feet thick, broken by 15 feet of shale. The Ames is not reported here, but it is present at 3 miles northeast, on the Morgan border, where it is 4 feet below the "Big Red." The Pittsburg coal is wanting at both places and no coal appears in the section for 180 feet above the place of the Ames. In one record a sandstone 35 feet thick and overlying a thin limestone is at 135 feet above the Ames, evidently belonging almost directly under the place of the Pittsburg. In the more northerly well the Cambridge is apparently about 125 feet below the place of the Ames, and so somewhat less than 300 feet below the Pittsburg. Macksburg, on the Noble County border, is at 17 miles northwest; there the Ames is 125 feet above the Cambridge and the latter is 363 feet below the Macksburg coal bed, which is about 90 feet above the Pittsburg. The first, or 140-foot, sand of this region, the Cowrun, is 35 feet thick at Macksburg and its top at a mile east in Noble county is 99 feet below the Ames. The interval from Pittsburg to Cambrdige is somewhat less than in western Washington. A great sandstone 78 feet thick begins at 176 feet below the Cowrun and continues to 523 feet below the place of the Pittsburg. This has been correlated with the Mahoning, but it belongs more probably in the Allegheny in part, for the bottom of the Mahoning in southern Monroe, 18 miles northeast, can not be placed lower than 480 feet below the Pittsburg.

Thirteen miles east of south from Macksburg and 15 miles southwest from Green township of Monroe county is Cowrun, in Lawrence township of Washington. The Cowrun uplift passes north and south through this township and exposes the Conemaugh to about 70 feet below the Ames limestone. Good exposures of the interval above the Ames are rare, but Professor Andrews found a limestone at 98 feet below the Pittsburg, 136 feet above the Ames in both Lawrence and Newport townships, and in the latter a coal bed at 40 feet above the limestone, which is at the

* E. B. Andrews: Vol. i, pp. 264-265, 270, 273-274, 278, 280, 289.
E. Lovejoy: Vol. vi, pp. 632-633, 645-646.
J. A. Bownocker: Bulletin no. 1, pp. 132-133.

place of the Jeffers coal of Gallia county—probably a Little Pittsburg. He gives a record from Lawrence near Cowrun on the authority of the late F. W. Minshall, for whom the well was drilled. The section, beginning at 140 feet below the Pittsburg coal bed, is:

	Feet.	Inches
1. Alluvium	22	0
2. Red and blue shale	74	0
3. Fossiliferous limestone [Ames]	1	6
4. Yellow shale	18	0
5. Coal [Harlem]	Thin	
6. Interval	20	0
7. Sandstone	30	0
8. Clay	4	0
9. Interval, coal [Brookville] near bottom	377	0
10. Sandstone	130	0

Here one has the "Big Red" over the Ames, and the Harlem coal is at 256 feet below the Pittsburg. The interval to the Ames is as large as that to the Cambridge along the western outcrop, which misled Andrews into identifying this limestone with the Cambridge. The bottom of the sandstone, Number 7, regarded by him as the Cowrun, is 305 feet below the Pittsburg coal. In the record of the Centennial well published by Professor Bownocker the top of the Cowrun sandstone is 314 feet below the Pittsburg, and that bed is 47 feet thick, resting on 23 feet of red shale. The bottom of the "Big Red" is at 223 feet. A sandstone 10 feet thick at 479 feet is at the place of the Mahoning. There is no thickening of the measures here as compared with more northerly localities, for the Brookville coal bed, at 705 feet in the Monroe well, is here at 701, and in the Minshall well at about 686 feet. The bottom of the sandstone below this coal is 814 in the Minshall well, 828 in the Centennial, and 800 feet in one of the Monroe wells.

Going southward into Newport township, one finds on the Ohio river Professor Andrews' section of the Ames and associated rocks, which is almost exactly the same as in the Minshall boring. In a well near by, drilled for Mr Minshall, the Harlem coal bed rests directly on 44 feet of pebbly sandstone, below which for 210 feet are blue and red shales resting on 100 feet of sandstone, beginning at 508 feet below the Pittsburg, and at 709 feet is the Brookville coal, with black shale resting on 120 of sandstone to 828 at the bottom of the well. The 100 feet of sandstone must be taken as belonging within the Allegheny. At 6 or 7 miles northwest from this locality and at the same distance west from the Cowrun wells is the record of a well at Marietta published by Professor Orton. There the Pittsburg and the "Big Lime" are wanting and the

only horizons to be depended on are the "Big Red" and the Brookville coal bed at the bottom of the Allegheny. The succession is:

		Feet
1. Sandstone		20
2. Red rock		95
3. Sandstone		35
4. "Big Red"		100
5. Shale		20
6. Red rock and slate		150
7. Red sandstone and mud		40
8. Mahoning sandstone	10 feet	
Mahoning black shale	20 feet	60
Mahoning sandstone	30 feet	
9. Slate		15
10. Sandstone		80
11. Slate		105
12. Sandstone		30
13. Slate and shale		15
14. Coal bed		5
15. Slate		25
16. Sandstone		70

Here one has the little coal bed of the other wells. The high red bed is that associated with the Pittsburg coal at many places in Ohio, while the overlying sandstone is the Pittsburg sandstone, which farther west and south approaches very closely to the coal. The place of the Ames is in the upper part of Number 6. The Cowrun sandstone is wanting and the Mahoning is represented by Number 8.

Four miles below Marietta, along the Ohio river, one has a partial record published by Doctor White:

	Feet
First Cowrun sandstone	23
Interval	157
Sandstone	100
Interval	90
Second Cowrun sandstone	15

Professor Bownocker says that the highest sandstone, at its bottom, is about 100 feet below the "Big Red," 85 feet thick and overlying a thin limestone which he thinks may be the Ames. The middle sandstone would be about 520 below the Pittsburg and equivalent to that in the Minshall well of Newport township, belonging therefore to the Allegheny, there being no sandstone here at the Mahoning horizon.*

* E. B. Andrews: Vol. ii, pp. 497, 502-503, 505.
E. Orton: Vol. vi, p. 399.
I. C. White: Geology of West Virginia, vol. i, pp. 286, 288.
J. A. Bownocker: Bulletin no. 1, pp. 134-136, 169, 175-176.

Returning to the western outcrop: A few insignificant areas in Vinton county reach to the Cambridge limestone, which is gray fossiliferous and 108 feet above the Shawnee or Upper Freeport limestone. Coal beds are at 31 and 50 feet below it, possibly Brush Creek, and that at an upper horizon dividing the Buffalo sandstone as at some localities farther north. But here, as in Jackson county, where Professor Orton found a coal bed at 93 feet above the Upper Freeport and underlying a conglomerate, the section is a single instance and so far from any other exposure that no positive identifications can be made.*

In Meigs county, south from Athens and extending eastward from Jackson to the Ohio river, one finds the Conemaugh deeply buried in the eastern portion, but exposed in the western. In this area, as in southern Athens, the Pittsburg sandstone overlies the Pittsburg (Pomeroy) coal or is separated from it at most by 17 feet of sandy shale. Professor Andrews gives many sections. Seven miles west from Pomeroy the Ames and Cambridge limestones are respectively 147 and 236 feet below the Pittsburg coal bed, but nearer Pomeroy the latter interval is only 221. In the western townships the Cambridge is frequently a "whitish fossiliferous" limestone, and a coal bed at the Harlem horizon often appears about 60 feet above it. At 25 feet below the Cambridge is a coarse sandstone and conglomerate, of which 30 feet were seen; it is in the place of the Buffalo sandstone, which belongs under the Lower Cambridge limestone of southern Ohio, the Cambridge limestone of Pennsylvania and northern Ohio. Mr Lovejoy finds the Cambridge limestone double in the northwest part of the county, but the lower division becomes very uncertain at a little way south. The Upper Cambridge, 27 feet above the Lower, is 112 feet above the Upper Freeport within the interval, the Anderson at 19 and the Brush creek at 45 feet below it. At another locality, 2 miles away, Professor Andrews found the Upper Cambridge at 47 and 109 feet above the Brush Creek and Upper Freeport coals.

Five or six miles west from Pomeroy, red shale, 19 feet thick, is at 50 feet below the Pittsburg, and a coal bed near the Barton horizon is at 203 to 205 feet. Red shale is exposed above the Ames at one locality, and at another that limestone overlies a bed, 35 feet, the place of the Pittsburg reds. The Mahoning is often sandstone, and Mr Lovejoy gives it as 56 feet in one measurement. The whole thickness of Conemaugh at 6 miles west from the Ohio river is about 350 feet.

Professor Orton publishes the record of a well drilled at Pomeroy, beginning 64 feet below the Pittsburg coal bed. The record is im-

* E. B. Andrews: Report for 1870, p. 117.
E. Orton: Vol. v, pp. 1025-1026.

portant because the samples were carefully examined and tested when brought up. Pomeroy is 6 miles east from the locality at which Professor Andrews found the Ames and Cambridge 147 and 236 feet below the Pittsburg. In the boring, red rock 38 and 42 feet was found beginning at 93 and 151 feet below the Pittsburg, the latter being the "Big Red" belonging above the Ames. A fossiliferous limestone at 285 is the Cambridge, the interval being 47 feet greater than at the western locality. The Cowrun sandstone overlying the Cambridge is coarse. The Mahoning (Lower) sandstone is at 379 to 431 feet, a more or less pebbly rock, while the great sandstone of the Allegheny begins at 15 feet lower, as in Newport township of Washington, and the Brookville coal bed is at 675 feet. Dark shale overlying limestone is reported directly under the Mahoning and it may be the Upper Freeport, thus giving a little more than 430 feet as the thickness of the Conemaugh—an increase of nearly about 70 feet in six miles—while it is 50 feet less than in eastern Washington county and the interval from Pittsburg to Brookville is also 40 feet less. The boring does not reach to the "Big Lime," which, at a point 6 miles southeast, is at 1,190 feet below the Pittsburg coal bed. At Pomeroy one is 40 miles southwest from Marietta.*

Passing over into Gallia county, extending along the Ohio river south from Meigs and adjoining Mason county of West Virginia, one finds near the western border an outlier of the Pittsburg coal bed with the Cambridge limestone at 240 feet below it. This is in Perry township, 10 miles west from Gallipolis, on the Ohio, and 20 miles southwest from Pomeroy. About 6 miles farther north, according to Professor Orton, the limestone is again double, the interval between the divisions being 18 feet. At 57 feet below the Upper Cambridge is a coal blossom which is 77 feet above the Upper Freeport, while at 28 feet above the latter is a limestone, thus making the thickness of the Conemaugh about 375 feet—an increase of about 25 feet over the average in Meigs. At about 5 miles northwest from Gallipolis the Cambridge is 248 feet below the Pittsburg (Pomeroy) coal bed and is, as in much of Meigs, a white limestone. The Ewing limestone was seen, at about 4 miles west from Gallipolis, 183 feet below the Pittsburg and underlying 20 feet of red shale. Another measurement only 2 miles from Gallipolis shows the Cambridge at 200 feet below the Jeffers coal, or about 250 feet below the Pittsburg, and red shale 16 feet thick is at 30 feet above it. Two feet of limestone at 50 feet above the Cambridge may represent the Ewing. The place of the Ames

* E. B. Andrews: Vol. i, pp. 249, 250-253.
E. Orton: Vol. vi, p. 397.
E. Lovejoy: Vol. vi, p. 633.

limestone is concealed in the sections by Andrews and Gilbert, but it was seen by Mr Lovejoy in the northern townships, along the Meigs border, at 5 or 6 miles southwest from Pomeroy. The Jeffers coal, separated by 40 to 50 feet of sandstone and shale from the Pittsburg, occasionally attains economic importance in the eastern part of the county, where it is accompanied by a persistent impure limestone 1 to 10 feet below it. Near Gallipolis a bed of red shale 20 feet thick begins at 132 feet below the Pittsburg, very near the horizon of the "Big Red."†

Lawrence county is south from Gallia and extends along the Ohio river, adjoining Cabell and Wayne counties of West Virginia and Boyd of Kentucky. The section, as measured by Mr Emerson McMillin near Greasy ridge and Arabia, about 12 miles north from Central City, in West Virginia, and nearly 20 miles west of south from Gallipolis, is:

		Feet.	Inches
1. Pittsburg coal			
2. Interval		150	0
3. Ames limestone	2 to	4	0
4. Interval		92	0
5. Slate coal		2	6
6. Interval		35	0
7. Cambridge limestone		3	0
8. Coal bed [Anderson]		3	0
9. Shale	10 to	25	0
10. Lower Cambridge limestone		3	0
11. Shale		6	0
12. Sandstone [Buffalo]		42	0
13. Coal bed [Brush Creek, Upper]	3 to	4	0
14. Clay		4	0
15. Shale		20	0
16. Coal bed [Brush Creek, Lower]		2	0
17. Ore bed [Mahoning]		2	0
18. Mahoning sandstone		20	0

to the Upper Freeport (Waterloo) coal bed, giving in all about 400 feet for the Conemaugh; but this is the minimum, the maximum being between 420 and 430 feet. The Upper Cambridge is at 280 feet below the Pittsburg, very nearly the same as in the Pomeroy well. The Slate coal bed is very near the Barton horizon, at which coal has appeared sporadically at many places along this western outcrop. In a personal communication, Mr McMillin states that the Upper Cambridge is comparatively pure, usually yielding a good lime, but the lower is always siliceous, often flinty, and frequently represented only by calcareous shale. The in-

* E. B. Andrews: Vol. i, pp. 232, 235-236.
E. Orton: Vol. v, p. 1049.
E. Lovejoy: Vol. vi, p. 632.

terval between the beds varies from 10 to 30 feet and the Anderson coal seems to be present generally; the coal Number 13 is from 28 to 50 feet below the Anderson. The Mahoning interval at times increases to 40 feet. In this part of the county the Cambridge is about 260 feet above the Vanport (Ferriferous) limestone.

The Cambridge limestone is very persistent and appears in many of the sections measured by Andrews and Gilbert in various parts of the county, sometimes single, sometimes double, the upper division separated from the Anderson coal bed by black shale. It is 230 feet above the Vanport (Ferriferous) limestone, on the Ohio river at about 3 miles below Ironton, the only direct measurement obtained along the river. At 7 miles north from Catlettsburg, Kentucky, the Upper Cambridge is 12 feet above the Anderson coal bed and 120 above the Upper Freeport. Measurements along the river or within 3 or 5 miles west or north from it are wanting, as the rocks are mostly soft and the slope rises in benches covered by loose material so deep as to mask everything.*

KENTUCKY.

Passing over into Kentucky, one finds Professor Crandall's generalized section for the northeastern counties as follows:

	Feet
1. Greenish sandstone and shale	60
2. Impure limestone [Ames (?)]	
3. Concealed	16
4. Coal bed 12 [Harlem (?)]	
5. Sandstone and Ore	55
6. Impure limestone [Upper Cambridge]	
7. Sandstone and shale	21
8. Coal bed 11 [Anderson]	
9. Sandstone or shale	39
10. Ore and Second Fossiliferous limestone [Lower Cambridge]	
11. Coal 10	
12. Sandstone, some shale [Buffalo and Mahoning]	60
13. Coal bed 9 [Upper Freeport]	

but the intervals vary greatly from those given in this section.

The Upper Freeport coal bed is absent from much of the area. Only the lowest members of the formation reach into Greenup county and the western outcrop passes through western Boyd and eastern Carter; the highest beds are reached in Lawrence county.

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* E. McMillin: Vol. v, p. 122. This section as published by Professor Orton has been modified in accordance with Mr McMillin's notes.
E. B. Andrews: Report for 1870, pp. 195, 204, 207.

The Lower Cambridge (Second Fossiliferous) limestone is at 60 to 95 feet above the Upper Freeport coal bed, the greatest interval being in northeastern Boyd and the least in southeastern Carter. The Upper Cambridge (Third Fossiliferous) limestone is 50 to 60 feet above the Lower. Doctor White finds at Catlettsburg a dark fossiliferous limestone 160 feet above the Upper Freeport coal bed, evidently the Upper Cambridge, as at a little way southwest Professor Crandall measured 159 feet as the interval. Mr McMillin's section in southeastern Ohio gives the interval to Lower Cambridge as 99 feet and that to Upper Cambridge as at most 131 feet, with the Anderson coal bed at 15 to 25 feet above the Lower. The interval between the limestones has almost doubled in 15 miles. Coal bed 10 is present at many places almost directly under the Lower Cambridge limestone; this is a new horizon, apparently without coal in other states, except perhaps in Wayne county of West Virginia. The interval between Upper Freeport coal and Lower Cambridge limestone is frequently filled with sandstone in Boyd county, the upper portion, equivalent to the Buffalo sandstone, being ordinarily very coarse, as in southern Ohio. No representative of the Brush Creek coal is reported anywhere except in southeast Carter, where at one locality a thin coal bed was seen 45 feet above the Upper Freeport and underlying the coarse Buffalo sandstone; it is at the place of the Upper Brush Creek coal bed in Mr McMillin's section.

In northwestern Lawrence the Lower Cambridge is 70 feet above the Upper Freeport coal bed and 100 feet below the Fourth Fossiliferous limestone, which may be either the Ames or the Ewing limestone, both of which are persistent in southern Ohio. At one point on the East fork of Little Sandy the interval between Lower Cambridge and the Anderson coal bed is 50 feet; the coal is 3 feet 6 inches thick, but elsewhere in Lawrence as well as in Boyd the bed is unimportant. On Jourdans branch the Upper Cambridge, gray, is 50 feet above the Lower and 133 feet above the Upper Freeport. At 95 feet above the Lower Cambridge is a cherty limestone, the Fourth, at a short distance above a coal, which is the highest observed in this part of the state and may possibly be at the Harlem horizon. Elsewhere, as may be seen by reference to the generalized section, the intervals are greater. The highest deposits remaining are near Louisa, in the central part of Lawrence county, where one finds greenish beds above the place of the Fourth limestone. At Louisa the Upper Cambridge is 200 feet above the Lower Freeport coal bed, 190 feet above the Upper Freeport (Shawnee) limestone. The Fourth limestone may disappear as limestone not far south from Louisa. In the northwestern part of the county it is a fossiliferous limestone; on Jourdans

fork it is represented by cherty limestone, but near Louisa its place is occupied by green calcareous sandstone. The Lower Cambridge limestone is present at 12 miles south from Louisa, near the line of Johnson county.

Coarse rocks occur commonly between the Upper Freeport and the Lower Cambridge in the northern part of Lawrence, but southwardly the deposits are finer and there is little of coarse material. Red shale is reported only from Catlettsburg, in northeast Boyd, where it underlies the place of the Upper Cambridge.

Southward from Lawrence county the section is uncertain. The anticline in Johnson and southern Lawrence has led to removal of Conemaugh and much of Allegheny from a broad strip, beyond which at present correlation is impossible. It seems altogether probable that some Conemaugh remains in Pike county; it is possible that there may be some even in southwestern Virginia, but at present no correlation may be attempted. Mr J. M. Hodge's revised section in Wise county of Virginia shows that the material on which the writer depended for that area is unexpectedly incomplete, and that the plane of separation drawn between Pottsville and Allegheny in southwestern Virginia and the adjacent portion of Kentucky may be incorrect.*

WEST VIRGINIA

Returning to the east and entering West Virginia on the west side of Chestnut ridge, in continuation of the Third bituminous basin of Pennsylvania, one has Doctor White's Morgantown section, which, condensed, is:

	Feet.	Inches
1. Pittsburg coal bed		
2. Interval	34	0
3. Little Pittsburg coal bed	1	6
4. Sandy shale	17	0
5. Limestone [Pittsburg]	1	0
6. Interval	27	0
7. Sandstone and sandy shale [Connellsville]	60	0
8. Shales	20	0
9. Black shale [Little Clarksburg]	1	0
10. Clarksburg limestone	1	0
11. Shale and sandstone. 45 feet; Sandstone 20 feet } [Morgantown]	65	0
12. Elk Lick coal bed	3	0

* A. R. Crandall: Greenup, Carter, and Boyd counties, p. 25, plates 1, 26; figs. 1, 7; 30, fig. 4; sections 26, 47, 62, 65, 70-71, 78, 81, 85, 87; Southeast Kentucky coal field, p. 28.

J. M. Hodge in personal communication.

	Feet.	Inches
13. Shales and concealed	55	0
14. Ames limestone	1	6
15. Variegated shale	85	6
16. Cambridge (?) limestone	1	0
17. Shales	14	0
18. Buffalo sandstone	3	6
19. Shale and shaly sandstone	30	0
20. Mahoning sandstone	100	0
21. Shales	40	0

to the Upper Freeport—in all, 561 feet. The Mahoning deposit continues upward, so as to pass the place of the Brush Creek coal and limestone. Nine miles south from Morgantown the Conemaugh is said to be 587 feet thick, the increased thickness being above the Ames limestone. The Brush Creek coal bed is at 99 feet above the Upper Freeport and underlies directly the massive Buffalo sandstone, which is 53 feet thick. The Barton and Anderson coal beds and the Cowrun sandstone do not appear in these sections.

Westward from the Monongahela one is dependent wholly upon the records of oil borings. Possibly because these are very numerous, the variability of the sandstones and red beds is much more marked in them than in the less numerous measurements of exposures. It may be that some of the variations are due to the inaccuracy of measurements by the drillers. In any event, it is necessary at the outset to state that while it is not altogether difficult to recognize any given sandstone horizon, still the correlation is never wholly exact, since, using the Pittsburg coal bed as the fixed horizon, one finds the top or bottom of each sandstone shifting in such fashion that the determination can not be in close detail. The limestones, so important in tracing the section by exposures, are very thin and do not appear in the records. The coal beds quickly become indefinite and disappear, while the red beds are distributed with such irregularity that they seem to mark localities of lagoons.

In Monongalia and Marion counties, west from the Monongahela river, the interval from Pittsburg to Upper Freeport varies from 560 to 578 feet. In the former county at 10 miles northwest from Morgantown it is 570 and in the latter at 12 miles southwest it is 578 feet. The Morgantown sandstone is well defined in many records and varies in thickness from 50 to 120 feet, its top being at 140 to 160 feet below the Pittsburg; yet in not a few records it is represented only by shale. The Cowrun sandstone, overlying the Cambridge limestone, does not appear in the Monongalia wells except near the western border, but it is recorded occasionally in the Marion wells at about 350 feet below the Pittsburg.

The Buffalo, on the other hand, is persistent though variable, sometimes replacing the underlying shales and encroaching upon the place of the Upper Mahoning. Its top is from 382 to 387 in Monongalia, 380 to 407 in Marion, the bottom being from 395 to 430 in the former and from 406 to 457 in the latter, the thickness of the sandstone varying from 5 to 50 feet. The Mahoning interval is more variable than the Buffalo. Typically it has two sandstone plates, upper and lower, separated by shales; the lower is the more persistent, the upper being replaced by shale very frequently; but in some localities the whole interval is occupied by massive sandstone. Ordinarily one finds between the sandstone and the Upper Freeport from 10 to 40 feet of shales, but occasionally the shale is replaced and the sandstone rests directly on the coal bed. The top of the Mahoning sandstone in Monongalia is from 421 to 475 feet below the Pittsburg, but from 436 to 515 feet in Marion; the bottom in Monongalia is from 515 to 521, in Marion from 538 to 578 feet, in the last case extending downward to the Upper Freeport.

The Anderson coal horizon is marked by a coal bed at 375 feet, reported in a Monongalia well, and a coal at 275 in a Marion well is very near the place of the Harlem.

The red beds in northern Monongalia are immediately under the Morgantown sandstone, 245 or 265 feet below the Pittsburg coal, to 330 or 340 feet, thus including the "Big Red" of Ohio overlying the Ames and the Pittsburg reds underlying that limestone. In southern Monongalia and in Marion red beds occur in some portion of this interval at almost all localities and occasionally higher beds appear—in one well at 86 to 111 feet, in two others at 127 to 230 feet, and in a third a great bed is at 161 to 326, replacing the Morgantown sandstone. The lowest bed recorded is in a well on the Marion-Monongalia border 341 to 381 feet below the Pittsburg. This is wanting in other records.*

In western Marion, on the border of Wetzel county, there appears at one locality to be only shale for 603 feet below the Pittsburg to the Butler or Upper Freeport sandstone, or possibly the (Lower) Freeport sandstone. Crossing over into Wetzel county, one finds, at 10 miles southwest, the only sandstone at 480 to 510 feet, while midway between the wells this sandstone is at 500 to 515 feet, the Lower Mahoning. Eight or 10 miles northward the sandstones are at 406 to 446 and 470 to 548 feet, and at 10 miles northwest, on the Marshall border, the only sandstone is at 509 to 569, with the Lower Freeport coal bed at 575, the place of the Upper Freeport in eastern Monongalia and Marion. The sand-

* I. C. White: Geology of West Virginia, Monongalia county, vol. i, pp. 234-236; vol. ia, p. 134; vol. ii, pp. 230, 269; Marion county, vol. i, pp. 238, 240, 242, 245, 247, 348.

stone at the last two localities includes the Butler and the Lower Mahoning. On the Marshall border a well shows a sandstone 37 feet thick beginning at 318 feet, which is at the place of the Cowrun.

Six red beds are recorded midway in Wetzel, in all 109 feet thick. A double bed begins directly under the Pittsburg coal and three others are in the interval, 166 to 383 feet. The lowest is 25 feet thick, beginning at 443 feet, so that it extends into the Mahoning interval.

Passing over into Tyler county, south from Wetzel along the Ohio river, one finds in the northern part of the county the first sandstone at 490 to 515 feet below the Pittsburg coal bed. Three miles southwest a double sandstone is at 440 to 480 and the first coal bed is at 704 feet, underlying a great sandstone extending from 529 to 664 feet. The same condition is found in another boring 3 miles farther west, where the first sand is at 437 and the second at 537, while near the Ohio the sands are at 425 and 555 feet. Three miles north in Ohio the sandstones are at 430 to 480 and 535 to 685 feet.

In eastern Wetzel one has reached the area of decreasing intervals. The bottom of the Mahoning there is at most 515 feet below the Pittsburg, as also in northern Tyler. Westward toward the Ohio river the thickness of the Conemaugh decreases until it is barely 500 feet. The conditions in Monroe county of Ohio amply confirm Doctor White's correlation of the Tyler "Cowrun" sandstone with the Mahoning. The coal bed at 704 feet below the Pittsburg, in Tyler, is the Brookville, at the bottom of the Allegheny.

In this region and in Pleasants county, west from Tyler along the Ohio river, one finds the condition already noted in description of the Allegheny, the prevalence of sandstone, which in some cases is continuous from the top of the Mahoning interval to the Pottsville. The red beds of Tyler and Pleasants can not be traced readily, as details are given in very few records. Two beds are noted in Tyler, 52 and 6 feet thick, beginning at 148 and 294 feet, in all 58 feet thick; but in Pleasants there are 75 feet within the interval 148 to 300, the mass being almost continuous from 80 to 195 feet below the Pittsburg. The only traces of coal in Tyler and Pleasants are at 148 in the former and 345 in the latter, marking the Little Clarksburg and Anderson horizons.*

Returning now to the east, the section may be traced westward through the next tier of counties—Taylor, Harrison, Doddridge, Ritchie, Wirt, and Wood—to the Ohio river opposite Washington county of Ohio.

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* I. C. White: Geology of West Virginia, Wetzel, vol. i, pp. 339, 340-341, 343, 348; vol. *ia*, pp. 176-177, 200-203.
Tyler: Vol. *ia*, pp. 241-242, 255-256, 258, 266-267.
Pleasants: Vol. *ia*, pp. 269, 273, 274, 286.

At Grafton, in Taylor county, 20 miles south from Morgantown and in continuation of the Pennsylvania Second bituminous basin, the Ames limestone, Harlem coal bed, and the Pittsburg reds are well shown, the last being 30 feet thick. A massive pebbly sandstone is at 25 feet above the Ames, and another, at 190 feet below that limestone, rests on dark plant-bearing shales with a thin coal at the bottom, the coal being at 250 feet. Two miles south, at Webster, the Ames is at 308 feet below the Pittsburg, and a thin coal bed is at 195 feet below the limestone, underlying calcareous and black shale. This is 120 feet above the bed identified on a previous page as the Lower Freeport, and the Mahoning interval is filled mostly by shale. The thin coal at Grafton appears to be at the Upper Freeport horizon and that at Webster is the Brush Creek.*

Harrison county, west from Taylor, is south from Marion. Near Clarksburg, 15 miles west from Grafton, the interval from Pittsburg to Upper Freeport is 540 feet, 35 feet less than at the nearest well recorded in Marion county. The first sandstone is at 365, 35 feet thick, and the Mahoning interval is marked by a continuous sandstone from 421 to 505 feet below the Pittsburg and resting on 35 feet of shale. This sandstone, in its upper part, reaches beyond the place of the Brush Creek coal bed and encroaches on the Buffalo interval, the higher sandstone reaching into the Cowrun. Two records are available in northern Harrison near the Marion line, where the Cowrun sandstone is persistent, its top being at 352 and 362; but in the latter case it is continuous with the Buffalo and downward into the Upper Mahoning at 457 feet. In both records the Upper Mahoning is almost wholly shale, and the Lower Mahoning sandstone, beginning at 492 and 512, extends downward into the Allegheny, its bottom being at 592 and 602 feet below the Pittsburg. The red beds are in characteristic contrast, for, though the wells are but 2 miles apart, the great bed of 100 feet seen in one at 102 feet below the Pittsburg is wholly wanting in the other, where one finds only a 40-foot bed beginning at 232 feet, which is represented in the former by 15 feet, beginning at 262 feet. This last is at the horizon of the "Big Red" of oil records in Washington county, Ohio. At West Milford, 10 miles south from Clarksburg, the first trace of coal is at 600 feet below the Pittsburg, probably at the Lower Freeport horizon in the Allegheny. Some red rock is at 95 feet and a 50-foot bed begins at 375 feet. At Cherry Camp, 10 miles west from Clarksburg, the only sandstone is 30 feet thick, beginning at 343 feet below the Pittsburg; all else is shale to a sandstone in the Allegheny at 642 feet. The higher sandstone is, at least

† I. C. White: Vol. ii, pp. 232, 298.

in part, at the Cowrun horizon. The red beds are thick, 43 and 50 feet at 119 and 208 feet respectively, the latter above the place of the Ames limestone and equivalent to the Ohio "Big Red." The Pittsburg reds do not appear in the Harrison County records.*

Doddridge county is west from Harrison and south from Tyler. Near Long run, 6 miles west from Cherry Camp, a thin sandstone is at the Morgantown horizon, but the Cowrun interval is filled with shale, while there is sandstone, 406 to 452, within the Buffalo; the Upper Mahoning is shale, the Lower Mahoning is sandstone in part, extending into the Allegheny at 589 feet, and the only red bed is one of 97 feet, resting on the Buffalo, which is in part the Pittsburg red. In northern Doddridge, near Center, several wells show a 30-foot sandstone just below the Connellsville horizon, but no other. The red beds vary; in three wells within a small area one finds them at

218 to 242..............	155 to 163..............	75 to 110
267 to 340..............	293 to 320..............	290 to 540

feet below the Pittsburg coal bed, while farther west, near the Tyler border, the whole red is in two beds, 15 and 30 feet, beginning at 235 and 411 feet respectively, only 35 feet in all, contrasting with one of the Center wells, in which the red is continuous from the Pittsburg reds into the Allegheny. At this western locality the Morgantown, Buffalo, and Mahoning intervals contain only 11, 25, and 20 feet of sandstone. In southeastern Doddridge, on the Harrison-Lewis border, one record shows sandstone in the Upper Mahoning at 440 to 480, but for the most part that interval holds only shale; sandstone is in the Lower Mahoning 35 feet thick.†

Ritchie county, west from Doddridge, is south from Tyler and Pleasants. The Pittsburg coal bed is of uncertain occurrence, but in areas where it is present the interval to the "Big Lime" of the Lower Carboniferous varies within sufficiently narrow limits to justify use of the lower horizon in tracing the section. Midway in the county, near Harrisville, as well as in the Whiskey Run district, 10 miles northeast, no persistent sandstone appears in the Conemaugh. At Harrisville a thick sandstone overlies the place of the Pittsburg coal, but no other sandstone is recorded until the Allegheny is reached. In Whiskey Run area one well shows two thin streaks of sandstone in the Conemaugh; the others none. At Cairo, 3 miles west from Harrisville, sandstone is seen in one well continuing from 409 to 487, in another from 443 to 483, and in the latter

* I. C. White: Vol. i, pp. 248, 250; vol. ia, pp. 317-318, 325.

† I. C. White: Vol. i, pp. 321, 325, 328, 329, 331-332; vol. ia, pp. 282-284, 293, 295.

it rests on Black slate at the Upper Freeport horizon. In western Ritchie the sandstones are very uncertain, some wells showing only shales above the Buffalo-Mahoning, while others show occasional streaks, and in one well a sandstone 55 feet thick begins at 305 feet below the Pittsburg, representing in great part the Cowrun horizon. The red beds are as irregular as the sandstones. At Harrisville the first red is at 85 feet, and thence to 470 feet are three beds, 20, 170, and 165 feet—in all, 355 feet. In a well on Whiskey run the first red underlies the Pittsburg coal and is 40 feet thick; the second, representing the "Big Red" and Pittsburg reds, begins at 197 feet and is 150 feet thick, while a third, 30 feet thick, begins at 430 feet; but in a neighboring well the great middle mass is altogether wanting. The same contrast appears at Cairo, where thick beds in one well are wholly unrepresented in another barely half a mile distant. Coal beds are reported at various localities as occurring at six horizons below the Pittsburg coal bed. The last two are in the Allegheny. It would not be difficult to make correlations for the others, but except in the numbers, there would be no justification for such correlation. No coal beds are recorded in the Conemaugh of Doddridge; the records of Wetzel, Tyler, and Pleasants are almost equally barren, and the references to coal in the Ritchie records are uncertain, a great number noting no coal. If these coals be coal and not black slate, they can be only accumulations of drifted material at best and probably they bear no relation to the coal beds near whose horizons they occur.*

Wirt county is west and southwest of Ritchie. On the eastern border the Pittsburg coal bed is 1,260 to 1,278 feet above the "Big Lime," and the first sandstone, 15 feet, is at 408 to 423 feet; the second, 60 feet, begins at 553 feet below the Pittsburg. Three wells at Burning Springs, a few miles farther west, show a sandstone, 34 to 77 feet thick, whose top is at 686 to 688 feet above the "Big Lime," while the top of the thick sandstone beginning at 553 below the Pittsburg on the eastern border is at 725 above the "Big Lime." If 260 feet be taken as the interval from Pittsburg coal to Ames limestone, the sandstone near Burning Springs is 529 feet below the Pittsburg, for the Ames limestone is at the surface. There the sandstone is 99 feet below a 15-foot sandstone, while on the eastern border it is 130 feet below the same sandstone. The interval between Pittsburg and Ames is 235 feet at Cowrun, 30 miles north in Ohio, and the intervals increase in this direction. The upper sandstone is toward the top of the Upper Mahoning and the thick lower sandstone, persistent in much of the county, belongs within the Allegheny. The Harlem coal bed is shown near Burning Springs, where it underlies the Ames

* I. C. White: Vol. 1, pp. 302-306, 313, 317.

limestone and "large unbroken shells of *Allorisma*, *Myalina*, and other forms are frequently found embedded in the upper part of the coal itself, though still in contact with the overlying limestone." The Morgantown sandstone forms bluffs along the Little Kanawha river at 40 to 50 feet above the Ames. On the west side of the county the Mahoning interval contains a sandstone at 422 to 482 feet below the Pittsburg, present in wells near the junction of Wirt, Wood, and Jackson counties. The detailed records in Wirt county begin, for the most part, below the usual horizons of red beds, but one near Burning Springs shows the Pittsburg reds.*

Wood county, west of Wirt and Ritchie, adjoins Washington and Meigs counties of Ohio. The Conemaugh is buried deeply, the Pittsburg coal can not be identified with certainty in most of the county, the Pottsville varies greatly in thickness, and the "Big Lime" is absent in the western portions.

In western Wirt the interval from Pittsburg coal to "Big Lime" is about 1,260 feet, but under the Cowrun anticline of Washington county, Ohio, that interval varies from 1,107 to 1,181 feet, and where the Pittsburg coal bed reappears farther south the measurement is about 1,120 feet.

In the northern part of Wood county, about 2 miles south from Marietta, one finds the "Big Red" 100 feet thick and 118 feet above what seems to be the Cowrun sandstone, 22 feet thick, 130 feet above a micaceous sandstone, 76 feet thick and very like that at 4 miles west in Ohio. The Mahoning interval holds only shale. Midway in the county one finds the "Big Lime" at 1,220 feet below the top of a sandstone very like that which farther south either overlies the Pittsburg directly or is separated from it by a score of feet. This rests on a great mass of red shale, 175 feet thick, broken in one well by 40 feet of shale. This red bed, associated with the Pittsburg, has been mentioned as occurring in central Wetzel and in central Ritchie. Here it extends upward into the Monongahela formation. A second bed, 30 feet thick, begins at 220 feet in one well, 210 in another, and a third, 72 feet in one, 105 in the other, ends at 412 and 415 feet below the assumed place of the Pittsburg. In the former well sandstone, extending from 412 to 465 and resting on 25 feet of red rock, underlies the red bed, but in the other this space is filled by shale, and a double sandstone is at 465 to 510 resting on 30 feet of red rock. It may be that these sandstones are the same, the smaller interval due to disappearance of the shales in the western well. The lowest red is unquestionably in the Allegheny.

* I. C. White: Vol. ia, pp. 463, 465, 467-468; vol. ii, p. 261.

Five miles southwest from the last well is Parkersburg, where neither Pittsburg coal bed nor "Big Lime" is present; but the relations may be determined approximately as at Marietta, 10 miles north in Ohio. A sandstone is here, 31 feet thick and resting on "red, blue, and gray shales," 415 feet, succeeded by 70 feet of gray shales, in all 485 feet, to a great sandstone, 105 feet thick, and at 760 feet is a coal bed. This bed is 208 feet above the Salt Sand and 843 feet above the Berea, while at Marietta the intervals are 225 and 830 feet. At Parkersburg it is 275 feet below the top of the 105 feet sandstone; at Marietta it is 280 feet below the top of the sandstone, there taken to be the lower part of the Mahoning, which at Parkersburg is continuous with the sandstone below, though at Marietta separated from it by 15 feet of shale. Evidently the section shows no material change and the Conemaugh is about 480 feet thick. The most notable feature is the great increase of reds, the upper one extending, as at Marietta, into the Monongahela, while other beds of considerable thickness are in the Allegheny.*

Returning to the eastern outcrop in Barbour and Upshur counties, the section may be followed westward across Lewis and Braxton, Gilmer, Calhoun, and Roane, Jackson and Mason to the Ohio river.

In northern Barbour a record about 10 miles southward from Webster, in Taylor county, shows 607 feet from the Pittsburg to the Lower Freeport. Two coal beds are present at 274 and 331 feet below the Pittsburg; the upper one, resting on a thin limestone, has been correlated with the Elk Lick; the lower bed, 270 feet above the Lower Freeport, underlies red shales containing the Ames limestone, so that it is at the Harlem horizon. There is little sandstone in the Conemaugh, and the red rock, in all, can hardly exceed 35 feet and is distributed in several layers within the lower part of the formation; but near Philippi, in this county, the Mahoning interval contains a massive sandstone. Ten or 12 miles southwest, in northern Upshur, a record shows a coal bed, possibly the Harlem horizon, about 285 feet below the Pittsburg and 255 feet above what may be the Upper Freeport. This record begins at about 100 feet. In 396 feet it shows only 65 feet of sandstone and 46 feet of red rock, three beds of each. At a few miles south from Buckhannon, in this county, a coal bed is shown in the river hill at 110 feet above the Upper Freeport, underlying 30 feet of massive sandstone on which rest red shales—very like the Brush Creek coal bed and Buffalo sandstone.

On the Lewis County border a record beginning at 220 feet below the Pittsburg shows 125 feet of red rock at 245 feet below that coal, succeeded by shales which continue into the Allegheny. The mass of reds

* I. C. White: Vol. i, pp. 285, 291, 295-297.

marks the double horizon above and below the Ames limestone. Twelve miles farther south, near Ireland, in Lewis county, coal beds are at 240, 372, and 429 feet below the Pittsburg. Doctor White sees in the upper beds the Elk Lick and the Barton. It is worth noting that these beds are 4 feet 6 inches and 2 feet 4 inches thick, and that they yield good coal. Eastward the Conemaugh coals are insignificant. On the west side of Lewis county the Vadis record shows that the Morgantown sandstone, 80 feet thick and beginning at 226 feet, continues to beyond the Harlem horizon. Sandstone in the Mahoning interval is 39 feet thick and ends at 490 feet. No coal is recorded and the red beds are

125 feet, beginning at 101 feet below the Pittsburg;
38 feet, beginning at 362 feet below the Pittsburg;

but the great bed seen in eastern Lewis is not here.

The records in northern Braxton county are somewhat indefinite, as the distance from the Pittsburg to well curbs is not given exactly. A record said to begin about 350 feet below the Pittsburg shows two red beds, 10 and 30 feet at 71 and 91 feet from the surface, and a third, not measured, is at 145 feet; thence for 365 feet the record is "slate, red rock, and shells" for 365 feet. Other records in this area show a similar condition, so that the great sandstone of the lower Conemaugh, so conspicuous in eastern Braxton, is here replaced by shale.*

In Gilmer county one finds near Stouts mills, only a little way west from the Braxton line and 12 miles west from Ireland, in Lewis county, the Morgantown sandstone, 85 feet thick and ending at 274 feet below the Pittsburg. A coal bed is here at 325 feet, but its relations are obscure. The red beds are numerous and are distributed through the section; the highest begins at 99 and the lowest at 529 feet below the Pittsburg; three thin beds are in the interval of the highest bed at Vadis; a fourth bed answers to the lower one at Vadis, but the reds associated with the Ames limestone are wanting. There is little sandstone below the Morgantown. Fifteen or 16 miles southwest, near Rosedale, on the Braxton border, are the records of a number of wells, all beginning at 100 to 150 feet below the Pittsburg coal bed. Taking the latter as the interval, the first sandstone, 126 feet thick, begins at 184 feet and rests on 102 feet of red rock, which is separated by 38 feet of sandstone from 100 feet of "slate and red rock." The first looks very like the Morgantown sandstone and its underlying reds. In these wells sandstone is insignificant in the lower Conemaugh as well as in the Allegheny, yet at barely 10 miles southeast the shales are replaced very largely by sand-

* Geology of West Virginia: Barbour, vol. ii, p. 238; Upshur, vol. i*a*, p. 349; Lewis, vol. i, pp. 255, 257; vol. ii, p. 239; Braxton, vol. ii, pp. 391-392, 453.

stone. The boring at Glenville, 8 miles northwest from Stouts mills, begins at the Morgantown horizon, but that sandstone is replaced and the record shows red beds extending from 192 down to 340 feet below the Pittsburg. Sandstone is unimportant, even that in the Mahoning interval being only 39 feet, ending at 534 feet below the Pittsburg. A coal bed at 444 feet may be the Brush Creek horizon. The Tanner well, in western Gilmer, shows that the sandstones are wholly insignificant, but the red beds are more than 200 feet thick; a similar condition is shown by records in southwestern Gilmer near the Calhoun border.

The records in Calhoun are a little obscure and determinate boundaries between the formations can hardly be set. The sandstones are variable, one record showing 83 feet in three beds, while another shows 152 feet in four beds. The red beds are important, but they are differentiated in only one record which shows

111	feet,	beginning	at	53	feet	below	the Pittsburg;
20	"	"	"	169	"	"	" "
71	"	"	"	214	"	"	" "
10	"	"	"	338	"	"	" "
122	"	"	"	403	"	"	" "

the place of the Pittsburg bed being assumed, as the bed is absent; the reds make up at least three-fifths of the Conemaugh section. A coal bed appears in one record at 113 feet below the assumed place of the Pittsburg.

In Roane county, west from Calhoun, the Spencer record shows only 40 feet of sandstone in the Conemaugh, and the first great sandstone is at 495 feet, most probably wholly in the Allegheny. A great red bed, 140 feet thick, begins at 153 feet below the place of the Pittsburg, which is represented in another well by 80 feet, beginning at 112 feet; lower beds are reported here and there in records, but they have no relation to each other. In a record obtained 10 miles southwest from Spencer the only red is a bed 35 feet thick, beginning at 55 feet below the place of the Pittsburg. Throughout the north and west parts of the county the sandstones are insignificant and coal is altogether absent.

Jackson county, west from Roane, is south from Wood along the Ohio river. The records are difficult to interpret, but less so for the Conemaugh than for the Allegheny. A record in the southern part of the county shows no sandstone in the upper part of the Conemaugh, but red beds are distributed throughout the formation. At Ravenswood, on the Ohio, 17 miles east from Pomeroy, Ohio, a coal bed, evidently the Pittsburg, is at 1,364 feet above the Logan sandstone. At Letart, 10 miles farther west, the Pittsburg is 1,354 feet above that sandstone. In con-

trast with Roane and eastern Jackson, sandstones are present, there being three beds, 44, 38, and 30 feet thick, beginning at 64, 316, and 364 feet below the Pittsburg; on the other hand, the reds have diminished to 56 feet in three beds, all above the middle of the formation.

At Letart, in Mason county, 10 miles west from Ravenswood and 10 miles southeast from Pomeroy, there is no sandstone in the upper part of the Conemaugh, the only beds being 12, 18, and 50 feet respectively, beginning at 350, 382, and 415 feet below the Pittsburg, the last being in the Mahoning interval.* The reds again become important in the upper half of the formation, there being a mass, 191 feet thick, which begins at 85 feet below the Pittsburg and includes the "Big Red" of Washington county, Ohio.

Returning now to the east: In Webster, Nicholas, eastern Braxton, and in Clay counties a bold sandstone overlies the Upper Freeport. In northern Webster the section extends 180 feet above the Upper Freeport, and deep red shale is shown in the uppermost 40 feet, but in the rest of the section the prominent feature is massive sandstone. At Powell mountain, in Nicholas, a massive pebbly sandstone is apparently continuous up to 180 feet above the Upper Freeport. Bold sandstone bluffs are on Elk river below Sutton, in Braxton county, and at Clay Courthouse the succession is:

	Feet
1. Concealed and much deep red shale	90
2. Coarse gray pebbly sandstone	60
3. Concealed and shales, some pale red	100
4. Massive sandstone, large quartz pebbles	60
5. Concealed and sandy shale	130

to the Upper Freeport coal bed. The sandstones are all pebbly and the lowest reds are about 200 feet above the Upper Freeport. In Webster the lowest reds are at 140, so that displacement of shale by sandstone reaches at Clay as far up as at Powell mountain, more than 15 miles eastward; but the record suggests that the sandstone is not continuously coarse as at Powell, rather that it is broken by sandy shale. Twelve miles below Clay Courthouse the top of "a great massive sandstone" is at 430 feet above the Brookville succeeded by red beds, evidently the same with Number 4 of the Clay section. A well record on the Roane County border 9 or 10 miles northwest from Clay shows red beds 60 feet, resting on an apparently almost continuous sandstone 330 feet thick, but not reported as containing pebbles.

* Geology of West Virginia: Gilmer, vol. i, p. 260; vol. i*a*, pp. 384-386; vol. ii, pp. 243, 388; Calhoun, vol. i*a*, p. 395; vol. ii, p. 396; Roane, vol. i, p. 264; vol. ii, p. 369; Jackson, vol. i, pp. 283-284; vol. i*a*, pp. 477-478; Mason, vol. i, pp. 281-282.

Along the Kanawha river the Conemaugh comes into the section at 2 or 3 miles below the line of Fayette county. Near lock number 3 155 feet of sandstone are above the Upper Freeport, and down the river coarse or pebbly sandstone appears above that bed wherever the horizon is reached, but becoming less coarse toward Charleston. A small area of what seems to be the Pittsburg coal bed exists below Charleston, and thence to the Upper Freeport the distance according to Doctor White's measurements is 643 feet. There is much massive sandstone up to 175 feet above the Upper Freeport, one section showing 75 feet of pebbly rock just above that bed and another showing 25 feet of similar rock ending at 175 feet. This condition continues for several miles, as a record at lock number 6 shows continuous sandstone for 405 feet above the Brookville-Stockton coal bed or to at least 200 feet above the place of the Upper Freeport. At Charleston the upper portion of the Conemaugh has about 120 feet of sandstone, much of it massive. There is much red shale, one bed about midway being 50 feet thick. This contains the "Two-mile" limestone, yielding fresh-water crustaceans. Two other thin limestones, non-fossiliferous, are here, but their relations are uncertain. Doctor White suggests that the "Two-mile" limestone may be at the Ames horizon. Two thin beds of impure coal appear in this section, but it is difficult to correlate them.

Mr Campbell gives the record of a boring at Winfield, in Putnam county, about 20 miles northwest from Charleston. The Conemaugh has five sandstone beds in the lower 300 feet, in all 105 feet thick. The Mahoning interval has a double sandstone, 10 and 35 feet, with 25 feet of shale intervening. The conditions characterizing the lower Conemaugh along the eastern outcrop have practically disappeared and the sandstone has been replaced largely by shale, while the sandstone which does occur seems to be without pebbles. Red shale is unimportant here, there being only three beds, 45 feet in all, and those are in the middle third of the formation.

The area of the Raymond City coal bed, taken usually to be equivalent to the Pittsburg, is very small and the coal thins away in all directions. Mr Campbell in working out the Huntingdon and Charleston quadrangles evidently hesitated to accept the reference of the coal bed to the Pittsburg, and in view of its circumscribed area was unwilling to take it as the plane of division between formations. Finding no other reason for separating the green and red shales and sandstones under the place of that coal from the similar rocks above it, he grouped the whole series above the Charleston formation into the Braxton formation. That formation in Putnam county and westward, where the upper part of the Charleston

sandstone has been replaced by shale, is equivalent to the Conemaugh and Monongahela formations and in some places may include a portion of the Dunkard.

Westward from the Kanawha river to the Ohio and in Putnam and Cabell counties the surface formation for the most part is evidently Conemaugh, but no details are available at present for closer description. There are many records of oil borings in Cabell, but in the absence of surface measurements they can not be connected up with the eastern localities. At Central City, on the Ohio, the Pittsburg coal bed is 340 feet above the river, but exposures are rare. The Ames limestone with all its characteristic features is present near Huntingdon and the Cambridge limestone is seen below Central City.*

Beyond the Kanawha, in southwestern West Virginia, one finds the full section of the Conemaugh only in Putnam county near Raymond, but the lower beds extend southward into northern Raleigh and apparently even into southern Mingo, so that they should be found in Pike county of Kentucky; but there are few details given in any of the reports.

Mr Campbell finds two coal horizons in Putnam county, one at 50 feet above the top of the Charleston sandstone and the other 300 to 400 feet higher. At Griffithsville, in eastern Lincoln, a coal is mined which he refers to the lower horizon. Mr d'Invilliers measured on Cobbs creek in this portion of Lincoln:

	Feet
1. Shales, sandstones and some red beds	150
2. Massive sandstone	25
3. Concealed, sandstone and red shale	150
4. Shales and stiff clay slates	75
5. Coal bed	6

This seems to be Conemaugh above the coal bed, which has been taken to be the Upper Freeport. Mr d'Invilliers's section in northern Raleigh has been given; it seems to show that a considerable part of the Conemaugh remains even there.

Doctor White finds the Ames limestone in the northwestern part of Wayne county, and at 3 miles from the mouth of Twelve-pole creek what appears to be the double Cambridge limestone is shown overlying the Kentucky Coal bed 10, which is only a few feet above the Buffalo sandstone. This limestone is shown frequently along the Big Sandy river from the mouth southward to Big Blaine creek, in Lawrence of Ken-

* Geology of West Virginia: Webster, vol. ii, p. 453; Nicholas, vol. ii, p. 459; Clay, vol. *ia*, p. 472; vol. ii, p. 289; Kanawha, vol. ii, pp. 240, 400, 502-503, 518, 522; Putnam, vol. ii, p. 401; Cabell, vol. *ia*, p. 495.

M. R. Campbell: U. S. Geol. Survey folios, Huntingdon, p. 3.

tucky. The conditions observed along the eastern border northward from the Kanawha appear in Mingo county, where one has 170 feet of sandstone, mostly pebbly, to calcareous red shales, which may be at the horizon of the Ames limestone and the Pittsburg reds. No trace of limestone is seen at more than 4 or 5 miles east from the Big Sandy.*

Allegheny and Conemaugh in the Anthracite Fields

SOUTHERN AND MIDDLE FIELDS.†

The column in the southern field is much longer than in the Middle, approximately 2,500 feet remaining in the deepest parts of the former, while only 1,500 feet are reported from the latter. The succession, descending, near Pottsville, in the Southern field, is:

	Feet
1. Brewery coal bed	
2. Interval	220
3. Salem coal bed	
4. Interval	100
5. Faust coal bed	
6. Interval	175
7. Tunnel coal bed	
8. Interval	165
9. Peach Mountain coal bed	
10. Interval	155
11. Yard coal bed	
12. Interval	70
13. Tracy coal bed	
14. Interval	46
15. Tracy coal bed	
16. Interval	65
17. Little Clinton coal bed	
18. Interval	55
19. Clinton coal bed	
20. Interval	110
21. Little Diamond coal bed	
22. Interval	40
23. Diamond coal bed	

* E. V. d'Invilliers: West Virginia and Ohio railroad, p. 9.
M. R. Campbell: Charleston and Huntingdon folios.
I. C. White: Vol. ii, pp. 259, 279, 280, 377.

† Detailed references to authorities will not be given for the anthracite fields. Descriptions of the coal beds, for the most part, have been compiled from Mr A. W. Smith's summary in the Final Report of the Second Survey; the features of the intervals between coal beds were ascertained by comparison of sections given in the atlases accompanying Report A A. The work by Messrs Ashburner, Hill, and Smith is so interlocked that one finds difficulty in assigning proper credit to each observer. Use has been made also of Mr B. S. Lyman's studies in the northern part of the Southern field.

	Feet
24. Interval	180
25. Little Orchard coal bed	
26. Interval	27
27. Orchard coal bed	
28. Interval	110
29. Primrose coal bed	
30. Interval	55
31. Holmes coal bed	
32. Interval	115
33. Seven-foot coal bed	
34. Interval	20
35. Mammoth coal bed	
36. Interval	75
37. Skidmore coal bed	
38. Interval	143
39. Buck Mountain coal bed	

each of the intervals being true only for the single locality at which the measurement was made.*

The Buck Mountain coal bed is the conventional boundary between Pottsville and higher measures, and it is taken here as the bottom of the Allegheny, to conform with usage in an earlier part of this work; but Mr David White has offered cogent reasons against accepting this plane of division. They will be referred to in another connection. The beds below the Holmes are known as "White ash," while that bed and those above are known as "Red Ash" beds. This distinction, however, is not absolute, as ash from the Mammoth and lower beds frequently shows the red tint.†

Several of the coal beds in both fields divide and subdivide even more perplexingly than do those of the Pottsville, in the Kanawha region, and intervals between the principal coal beds show abrupt variations. Were it not for great mining operations, extending continuously, in some cases for many miles, positive correlation would be impossible; but in those mines the "splits" have been followed as they separated and again united, so that no doubt remains respecting some of the most remarkable variations within the beds and in the intervals separating them.

The Buck Mountain coal bed is present in both fields. It is hardly recognizable in the western prongs of the southern field, but is 2 feet to 3 feet 6 inches thick just east from the union of the prongs, where it is slaty and impure; thence eastwardly it increases in importance until at Pottsville and beyond it is inferior only to the Mammoth, the thickness on

* Final Report, plate 366, opposite p. 2076.

† According to analyses tabulated by Mr Ashburner in Annual Report for 1885, pp. 314-315.

the northerly side being 13 to 19 feet, with 12 to 18 feet of good coal, as measured by Mr Lyman. Near Pottsville the bed is in three splits, with a total of 3 to 16 feet, but at Tuscarora, 8 miles east, the splits have united into a bed 10 to 17 feet thick. Still farther east two splits appear, 20 to 100 feet apart, which unite again eastward, and at the east end of the field the bed is from 9 to 12 feet.

In the western Middle, east from a line passing rudely north and south through Pottsville, the bed is important, 10 to 18 feet thick, and at the east end single. Westward it is less important and at Mahanoy City is in two splits 20 feet apart. Beyond this it decreases slowly on the southern side of the field, for at 14 miles it is still 4 to 5 feet thick. Northwestwardly from Mahanoy City the decrease continues for a short distance, but the bed recovers and at 10 miles northwest it is 15 feet thick; thence westwardly it loses steadily, becoming 6 feet within 4 miles, 2 to 10 feet, but with little good coal, at 7 miles, while at the western end it is a worthless mass of black slate. It remains available farther west in this than in the Southern field, for it is good enough to repay working at Shamokin, whereas it is worthless at 14 miles southeast, in the Southern field.

The variations of this bed in the eastern Middle are unlike those in the other fields. The bed is important to the northern border in the extreme eastern portion, showing at times 25 feet of coal; but westward, in a north and south strip 7 or 8 miles wide, it is worthless. This is north from the area of chief importance in the Southern field. Beyond this space it increases to its former thickness, and so continues to the western end, this portion being north from the important area northwest from Mahanoy City. The "splits" do not separate widely in the eastern Middle.

The Seven-foot coal bed of the Southern and western Middle is the Gamma of the Eastern. It is often thick, but, except near Mahanoy City, it is a mass of coal and slate in the former fields; it is sometimes 6 feet thick, with good coal, in the eastern part of the eastern Middle.

The Skidmore coal bed of the Southern, Wharton of the Middle, is persistent in the Southern field, where it is practically worthless except at the extreme east end, though occasionally workable at a little farther west. It is less irregular in the western Middle, where, however, it is important chiefly in the area northwest from Mahanoy City. Farther west in that field it is usually worthless except near Shamokin. In the eastern Middle it is good in the strip where the Buck Mountain is worthless, but is better farther west, where the lower bed also attains importance.

The Mammoth is the great bed of both fields. In the Southern, toward the end of the northern prong, it is but 2 to 4 feet thick; thence it increases and attains its maximum at the east end of the field, where, within a small area, its splits are united into one bed 114 feet thick with 105 feet of coal. Mr Ashburner's section at one locality toward this end shows three splits, 25, 13, and 8 feet, in a vertical distance of 83 feet; at another locality the splits are two, 57, and 16 feet, 95 feet apart, while at a third the bed is single and 115 feet thick. Similar variations occur in the Pottsville and Tremont areas, while northwest, in the Heckscherville area, the bed is in two or three splits in a vertical distance of 175 to 214 feet. In the western Middle, east from Mahanoy City, the splits are usually three in a vertical distance of 150 to 200 feet; but the intervals diminish westwardly until at Shenandoah the bed is single, 40 to 60 feet thick. Beyond that place the coal diminishes, and at Shamokin the splits are 8 and 7 feet and from 10 to 150 feet apart. Like the Buck Mountain and Skidmore, this is a coal bed much farther west here than in the Southern field. In the eastern Middle the Mammoth is thick everywhere except in a small area within the Black Creek basin, where it is only 12 feet. Ordinarily it is a single bed 20 to 60 feet thick, attaining its greatest thickness in the eastern part of the field; occasionally it is in two splits, never widely separated.

The Holmes coal bed is persistent in the Southern and western Middle, but it has not been recognized in the eastern Middle. It is from 3 to 17 feet thick and carries a great proportion of refuse, except in the extreme eastern part of the Southern and the western part of the western Middle, in both of which it is important and yields good coal.

The Primrose coal bed, like the Mammoth and the Buck Mountain, tends to divide, but the interval between the splits is never great. It varies greatly in thickness within the Southern field and, like the lower beds, decreases westwardly; yet it is more persistent in that direction than even the Mammoth, for at the last exposure in the northern prong it still has more than 2 feet of good coal. In the western Middle it has 6 to 7 feet of coal near Mahanoy City, but westward it is poor, until near Shamokin it becomes important with 7 feet of marketable coal. It is reached at only two localities in the eastern Middle and is not mined. At most places the coal is poor and the bed is known generally as the "Rough coal."

The Orchard coal bed is persistent in the Southern field, where, unlike the lower beds, it is best only near the beginning of the northern prong; elsewhere it is almost worthless. In the western Middle it is fit to mine only near Mahanoy City and Shamokin, but the refuse at the former

locality is almost 50 per cent, so that the bed is at its best only in the western part of these fields. It is not reached in the eastern Middle. The Diamond is a variable bed, occasionally workable in the Southern field, but disappearing in the western part. It has been recognized near Mahanoy City in the western Middle, but, unlike the lower beds, it seems to be wanting in the Shamokin area. The Tracy and Little Tracy show similar variations. These are the highest beds recognized in the western Middle. The Peach Orchard remains in an area so small that its variations are unimportant, but in the Pottsville and Llewellyn districts it is from 4 to 10 feet thick and is one of the best beds in the whole column, the coal being of exceptional purity. It was apparently the last important deposit, for, although the section extends 700 feet above it, none of the higher beds, excepting perhaps the Tunnel, appears to be worth working.

The important period of coal accumulation within the Southern and Middle fields ended with the Mammoth; for while the total amount of coal formed during the remaining time was probably as great, yet accumulation was continuous nowhere for long enough time to form a great bed over any considerable area. The irregular local movements causing the splitting of the Mammoth and Buck Mountain were no greater than those occurring in later intervals of similar length, as is evidenced by the varying intervals between higher beds. The variation is more striking in the Mammoth and Buck Mountain only because confined in each case to what becomes at times a single bed. It must be remembered that the time required for accumulation of coal in those beds was probably longer than that required for accumulation of half the mass above the Mammoth; so that the only cause for wonder is that, in any locality, the subsidence could be so slow and so regular long enough to permit accumulation of 105 feet of anthracite coal. Great variations in conditions existed during the formation of all beds except the Mammoth, for even the Buck Mountain shows a broad area in which the carbonaceous matter is distributed through a mass of coal slate, while some other beds, usually alternating thin layers of coal and slate, occasionally become sufficiently good to repay mining.

In this connection it is well to consider the variations in some intervals. The sections suggest that in the Southern field the intervals between Buck Mountain and Mammoth and between Mammoth and Holmes increase toward the west; but one may not offer a generalization, as complete presentation of details might prove this only an apparent condition. But variations in intervals below the Mammoth are important, as they are wholly clear in the multitude of sections gathered by

Messrs Ashburner, Hill, and Smith during their close study of the fields. In much of the Southern field the interval between Mammoth and Skidmore varies from 75 to 125 feet, but on the northern border, where that field is in contact with the western Middle, survey sections and those by Mr Lyman show:

	Feet.	Feet.	Feet.	Feet
Mammoth				
Interval	13	20	44	80
Skidmore				
Interval	43	61	27	23
Gamma				

these variations being in a distance of two miles and a half, the last at Mahanoy tunnel, on the border between the fields. In the western Middle the interval between Mammoth and Skidmore, west from Mahanoy City, varies from 6 to 33 feet. In the eastern Middle one finds this interval varying from 8 to 114 feet within a short distance, the Buck Mountain at the latter locality being 300 feet below the Mammoth. In the Hazleton basin, within a distance of 8 miles, one finds the interval, Mammoth to Skidmore, increasing westwardly from 35 to 41, 110, and 200 feet, the workings being continuous. While farther north, in the Black Creek basin, the interval between those beds varies from nothing to 50 feet, that from Mammoth to Buck Mountain varies from 66 to 200 feet in the same area. Thus in Little Black Creek basin the Wharton (Skidmore) is distinctly a split from the Mammoth, and the great decrease in interval to the Buck Mountain is such as to press the suggestion that that lower bed also unites with the Mammoth-Wharton somewhere in the eroded area.

The sections tell of great variability in coarseness of the material between the coal beds; limestone appears to be wanting everywhere; shale and sandstone, the latter often conglomerate, fill the intervals.

The material between Buck Mountain and Mammoth, in the eastern part of the Southern field, is for the most part sandstone, with at times immense beds of conglomerate; but near Pottsville slate predominates, while southeast from Tremont there is no conglomerate and more than half of the interval is filled with slate. Farther west the predominating rock is sandstone, with little conglomerate, but at Lykens, in the northern prong, conglomerate 48 feet thick is at 100 feet below the Mammoth. Beds of conglomerate fill intervals between the Mammoth splits at a number of localities. In the western Middle coarse material, sandstone, and conglomerate predominate east from the line of Mahanoy City; west from that line there is much variation. At times conglomerates are on the Buck Mountain and under the Mammoth, but near Shamokin the

interval shows only alternating shales and sandstones. In the eastern Middle sandstone, conglomerate, and comparatively little slate are at the south and east, but in the northerly and northwesterly basins shale appears abundantly in many sections, at times predominating.

Above the Mammoth there is much greater variation. In the eastern part of the Southern field conglomerate occurs only in thin beds, though one section shows 37 and another 78 feet of conglomerate near the Holmes. In some sections shales predominate for a long distance above the Mammoth and coarse beds appear only in the higher portions. In the eastern Middle, which is north from the eastern end of the Southern, sandstone prevails above the Mammoth, but even in the Southern basin, Beaver meadow, the proportion of slate is very large. At the north, in the Big Black creek basin, the coarsest rocks are midway in the basin and slates prevail on the western side. In the central part of the Southern field, near Pottsville, slates predominate to the Little Tracy at 1,450 feet above the Buck Mountain, the beds being from 25 to 100 feet thick, while the total of conglomerate is not more than 45 feet. Southeast from Tremont the interval, Mammoth to Orchard, shows fully 200 feet of slate in beds 10 to 33 feet thick, but fine conglomerate is associated with the Holmes, Primrose, and Orchard coal beds. The coals frequently succeed or precede a bed of conglomerate. In the sections beyond Pottsville, westward, there is little, aside from slate, to the Primrose, though occasionally a section shows more sandstone than slate, and even some thin streaks of conglomerate. Near the origin of the northerly prong sandstone is the rock for 60 feet above the Mammoth, beyond which there is mostly shale to the Orchard; but above that bed for 150 feet there is little aside from sandstone. Farther west, at Lykens, sandstone prevails to 400 feet above the Mammoth. In the western Middle, west from the line of Mahanoy City, fine sediments predominate above the Mammoth, there being alternating shales and sandstones; but one section near Shamokin differs from others in that region, as in 316 feet below the Holmes it shows but 60 feet of slate.

On the whole, materials are markedly coarser in the eastern parts of the fields; but even there the sections prove erroneous the opinion so long prevalent that shales are lacking, while in the greater part of the western areas shales are present in large proportion. The presence of so much coarse material in the northern prong has interest for the geographer.

NORTHERN FIELD

In the northern part of this field the Coal Measures column is but 400 feet, but the length increases southwardly until, in the deep basin between

Wilkesbarre and Nanticoke, there remains a thickness of about 1,800 feet. The lower coal beds seem to be fairly recognizable in the several basins, but much doubt exists respecting the higher beds. Even in the lower beds identifications must be made with hesitation at times, as the beds in splitting become thin and continuous workings are not possible. The succession and probably synonymy are as follows, descending:

Auble coal bed,
Snake coal bed,
Abbott coal bed,
Kidney coal bed,
Olyphant coal bed I, Brisbin,
Olyphant coal bed II, Richmond, Hillman (?)
Diamond coal bed,
Rock coal bed, Checker,
Pittston coal bed, Grassy island, Slope, Big, Baltimore,
Marcy coal bed, New County, Four-foot, Ross,
Shaft coal bed, Archbold, Clark, Four-foot,
Dunmore coal bed III, Clifford,
Dunmore coal bed II, } Dunmore, Red Ash, Buck Mountain.
Dunmore coal bed I,

The Dunmore coal beds are subject to great variation in the northern part of the field; six beds are shown in a vertical distance of 136 feet at Carbondale, of which one is workable, but farther north, at Forest City, all are thin. The interval from the Shaft coal bed to the top of the Pottsville, near Carbondale, is 125 feet, but at Forest City it is 180. Still farther southwest, near Priceville, Olyphant, and Blakely, the Dunmore beds are all thin, but at one locality on the northerly side they seem to have united into one bed with 14 feet of good coal, and the interval from Clark (Shaft) coal to Pottsville has increased to 260 feet. Toward Scranton three Dunmore beds are worked at 202 feet below the Clark (Shaft) coal, with a total of 16 feet of coal and partings in a vertical space of 32 feet; but these intervals are unusually small, as the Dunmore beds are distributed ordinarily in a vertical space of about 100 feet and highest one is from 170 to 35 feet below the Clark, this interval decreasing southwestwardly. In the Pittston area the Dunmore beds are represented by the Red Ash, or Powder Mill, coal bed, which is usually triple in the northeastern portion, the intervals between the splits varying from a few inches to 60 or 70 feet, though where the bed is double the interval rarely exceeds 20 feet. In the western portion the bed is usually double, with the splits, 5 and 4 feet, about 25 feet apart; but in the Boston colliery they are united with a thickness of 10 to 12 feet. In the eastern portion of this area the Clark is 80 feet above the top split, but in the

southwest, where the bed is single, the interval is 140 feet. The Red Ash becomes very important in the Wilkesbarre region, the splits uniting to make a bed 10 to 12 feet thick; farther southwest the thickness increases to 15 or 20 feet, occasionally swelling to 40 feet, though the interval between the splits sometimes reaches 50 feet. At the last exposure southward the bed is still 5 to 9 feet thick, and is known as the Buck Mountain.

The Shaft, Clark, or Archbold coal bed is double near Carbondale, where the interval between the "top" and "bottom" splits varies from nothing to 40 feet; but at the north end of the field, near Forest City, the bed seems to be always single. In the Priceville, Olyphant, and Blakely region it is single, 9 to 10 feet at the north, but decreasing southwardly to 3 or 5 feet, and at length to a mass of coal and slate which can hardly be recognized in the borings. Still farther southward it is important, becoming 10 to 12 feet near Hyde Park, in the Scranton area; but again it decreases, and in the Pittston area is 2 to 8 feet thick, with "Rough coal" so high in refuse that it is hardly worth mining. This deterioration evidently continues, for the bed seems to be unknown in the Nanticoke area at the south end of the field.

The New County, Marcy, or Ross coal bed is represented by the Four-foot coal bed of the Priceville area; but it becomes important first in the Scranton region, where at times it is from 7 to 9 feet thick, with 5 to 7 feet of good coal. It is good as far as Pittston, but thence deteriorates for several miles, though retaining its thickness. It varies greatly in the Wilkesbarre region, 4 to 20, and in one colliery even 40 feet thick. The interval to the Red Ash is 50 to 150 feet. The bed is sometimes in two splits, 5 to 10 feet apart; these diverge toward the Nanticoke area until they are 50 feet apart, with the thickness respectively of 15 and 9 feet; but this interval is very irregular. At the Wanamie colliery the bed is single and 15 to 25 feet thick; at Glen Lyon the splits are sometimes near enough to be mined as one bed, but followed westwardly in the tunnel they diverge widely. At Glen Lyon the interval to the Red Ash is 40 to 100 feet, increasing westwardly.

The Slope, Grassy Island, Big, Pittston, Baltimore coal bed is 130 feet above the Clark at Carbondale, though farther north, at Forest City, the interval is but 80 feet. In this northern part of the field the bed is about 5 feet thick, but it increases southwardly, so as to have a thickness of about 8 feet in the Jermyn basin, where the interval to the Clark has become 200 feet. In the Scranton area the "Big" bed averages 12 feet and is 100 to 150 feet above the Clark; farther southward, near Pittston, the "Pittston" coal averages 10 feet 6 inches and is 125 feet above the

Clark. The "Baltimore" coal of the Wilkesbarre area is believed to be the same bed; there it is often in two splits, the Bennett and Cooper, which are mined separately. When united, the thickness averages 20 feet. It is single from Wilkesbarre to Ashley, but splits northeast from the former place, the interval being 20 to 40 feet and the thickness of coal 16 feet. It is always split west from South Wilkesbarre, with only 10 feet of coal and the splits about 50 feet apart. The interval to the Red Ash is about 300 feet. The relations in the Nanticoke area are uncertain. A bed found there at 90 to 140 feet above the Ross, and known as the Twin, or Wanamie, is very near the place of the Baltimore; but it is so variable that some think it the equivalent of one of the thin beds seen above the Ross farther north. Two higher beds have been taken by some to be equivalents of the Bennett and Cooper splits of the Baltimore, and the beds bear those names. The lower one is 50 to 100 feet above the Twin and the other is 30 to 40 feet higher. The lower bed is mined at some places, 4 to 6 feet 6 inches thick, but the upper bed is extremely variable and of little importance. In any event, whether the equivalent of the Baltimore be the Twin or the higher beds, it is evident that the great bed has become insignificant in passing from Wilkesbarre to the Nanticoke area.

There seems to be a persistent coal horizon at 15 to 100 feet above the Big, or Baltimore, bed; it is the Rock coal of the Jermyn-Priceville area, traceable thence into the Pittston area, where it is known as the Checker. It becomes important here and there, varies from 6 to 10 feet, and generally yields rather poor coal.

In the Jermyn-Priceville area the sections show three coal beds above the Rock within a vertical space of about 200 feet; these are the Diamond, Olyphant 2 and 1. They yield good coal, but are rather thin. They have been recognized in the Scranton region, showing the same features. In the Pittston area a coal bed, the Hillman, is at an average distance of 175 feet above the Checker, 6 to 8 feet thick, and preserved in only a small space. A coal bed known as the Hillman occurs in the Wilkesbarre area at an average distance of 270 feet above the Baltimore bed, and is from 7 to 10 feet thick, with much clean coal. As the areas of the higher beds are very small near Pittston and Wilkesbarre, it is difficult to make correlation; but the Hillman of both Pittston and Wilkesbarre seems to be one bed and very near the place of Olyphant 2. A Hillman coal is in the Nanticoke region at 240 feet above the Twin coal. It is very near the place of the Wilkesbarre Hillman, if the Twin be taken as the Baltimore.

In the deep basin between Wilkesbarre and Nanticoke, there are above the Hillman several coal beds, some of which are fairly regular; but the accumulation of coal in available beds seems to have ceased at about 1,200 feet above the Red Ash bed and the higher measures are barren; southeast from Nanticoke to Dundee the upper measures for 900 feet have been proved by borings to be without workable coal.

Respecting the relations of the coal beds in this field to those in the others, nothing can be determined by stratigraphy; a gap of almost 25 miles separates the areas. The Red Ash and the Baltimore are supposed to be equivalent to the Buck Mountain and Mammoth respectively. The important Shaft, or Archbold bed, evidently disappears southward before reaching the Nanticoke area, and the Baltimore, the second important bed above it, becomes so obscure and uncertain that its equivalent in the Nanticoke region is still undetermined. The only coal beds retaining their importance are the Red Ash, or Dunmore; the Ross, which, owing to disappearance of the Archbold, becomes the second bed, and the Hillman. It has been seen that in the nearest portion of the eastern Middle the Mammoth and Skidmore prove to be one bed, and that the interval between that bed and the Buck Mountain is so diminished as to suggest that they may unite at but a little way northward. It seemed possible, therefore, to seek in the Red Ash of the northern field the equivalent of the Buck Mountain, Skidmore, and Mammoth; but this suggestion appears to be contrary to the evidence furnished by plant remains, as read by Mr David White, so that it may not be accepted. The solution of the problem remains with the paleontologist.

The material filling intervals between coal beds in the northern end of this field is for the most part rather fine. Sandstone prevails above the Clifford-Dunmore, and one section shows 51 feet of conglomerate resting on that bed; but, higher up, sandstone and shale are in alternating beds. Near Carbondale the sandstones are fine and the proportion of slate is large, but near Jermyn the sections show little aside from sandstone. This is the condition near Olyphant even to the Diamond coal bed. On the easterly border, near Winton, conglomerate appears in most of the sections between the Dunmore and Clark beds; but in the Priceville-Dunmore-Scranton region coarse rocks are usually wanting and shale is present in great proportion for 240 feet above the bottom. The change from sandstone to slate is very abrupt in many places and a record in Scranton shows a notable bed of conglomerate.

Farther southwest one finds a persistent conglomerate above the Red Ash in the Lackawanna-Pleasant Valley district; it is within the first 120 feet above that coal bed, and varies from 9 to 80 feet in thickness.

Sandstone predominates in the sections, though thick beds of shale are not wanting. Near Pittston and Wyoming the interval between Red Ash and Checker is filled with sandstone or with clay and sandstone, there being no coarse material aside from some thin streaks of conglomerate near Wyoming; but a conglomerate 18 to 42 feet thick overlies the Checker. Near Luzerne some sections show a variable conglomerate above the Ross, but for the most part there seem to be only sandstone and shale up to 520 feet above the Red Ash. Southeastwardly, however, near Wilkesbarre and thence toward the easterly edge of the field conglomerate appears in many sections between the Red Ash and the Baltimore, between Baltimore and Hillman, as well as above the last bed, and the conglomerates are thick, 10 to 130 feet. In some records no conglomerate is noted, but in all the deposits are coarse and there is little shale. Near Plymouth one record gives 86 feet of conglomerate between Red Ash and Ross, but other records, extending 800 to 1,300 feet above the Red Ash, show no conglomerate, while shales or clays make up nearly half the mass. Near Ashley and Sugar Notch, southeast from Plymouth and toward the easterly border, conglomerate is reported occasionally, but not as in the Wilkesbarre area on this side of the field, and the interval, Red Ash to Baltimore, is filled usually with sandstone, while shales become abundant higher up in the column.

Conglomerate appears between Red Ash and the place of the Baltimore near Nanticoke and Glen Lyon, at the southern end of the field, sometimes resting on the Red Ash, and in one case very near the "Bennett." Still, many records show only sandstones in this interval. Deposits are finer above the place of the Baltimore, and there is much shale.

Limestone occurs only in the upper part of the column, and seems to be confined to the Wilkesbarre-Nanticoke region. The first notice of this limestone was by Mr Ashburner, who gave a section which, condensed, is as follows:

	Feet
1. Slate, thin coals, and sandstone	138
2. Mill Creek limestone	1
3. Sandstone	25
4. Canal limestone	2
5. Slates, sandstones, and coal beds	134
6. Limestone	2
7. Slate, sandstone, conglomerate, coal beds	155
8. Hillman limestone	3
9. Slate	10
10. Hillman coal bed	16
11. Conglomerate, slates, sandstone, coal beds	341
12. Coal bed E, Baltimore	16
13. Sandstones, conglomerates, coal beds	351

in all 1,194 feet to the Pottsville. The fossils were obtained from the Mill Creek limestone, which is about 700 feet above the Baltimore coal bed; the other limestones, so far as known, are non-fossiliferous.* The collections were examined by Professor Angelo Heilprin, who gave a list of about twenty species. Comparison of these forms with those obtained in southwestern Pennsylvania and the adjacent portion of West Virginia leads to no positive conclusion respecting the place of the limestone. Three forms, *Eumicrotis hawni, Monopteria gibbosa,* and *Chonetes millepunctata,* have not been reported from any other locality in the Appalachian basin. The other forms are widely distributed, most of them having been found below the Mahoning interval. Somewhat similar grouping of forms occurs in a black shale near Dundee, which Mr Hill places about 250 feet above the Mill Creek limestone. As far as the testimony of these fossils is concerned, the Mill creek is as likely to be Allegheny as Conemaugh; but the coal-making period seemed to have ceased in great measure after the Hillman bed, so that here one finds conditions characterizing the Conemaugh in the bituminous areas.

It seems altogether probable that the higher beds of the Northern fields are wholly unrepresented in the Southern field. In an earlier part of this work it was seen that the Pottsville diminishes northwestwardly, so that the vast pile of the Southern is represented by a very short column in the Northern field. In the higher measures one finds that the interval, Buck Mountain to Tracy, diminishes almost to one-half in passing from the neighborhood of Pottsville into the western Middle. If the change continue in this upper portion as in the Pottsville, the great column of the Southern field should be represented by less than the lower half of the column in the Northern field; so that one might regard the rocks above the Hillman coal bed as without equivalent in the Southern field.

* Annual Report for 1885, pp. 449 et seq.

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PALEOGEOGRAPHY OF SAINT PETER TIME

BY CHARLES P. BERKEY

(*Presented by title before the Society December 29, 1905*)

CONTENTS

INTRODUCTORY STATEMENT

The Saint Peter sandstone is one of the most prominent Ordovicic formations of the Mississippi valley. Because of its striking characters it has attracted comment from almost every geologist whose work lay within this territory. Most of them have been led to suggest an explanation of its remarkable purity, or its apparent uniformity, or its structural relations. Many have regarded the formation one of the most puzzling of the region, the obscure problem being that of origin.

The following study is primarily one of the physiographic conditions represented in Saint Peter time. It has led to a comparative study of this formation as described from many localities and by many observers.

This data has been checked wherever possible by the writer's own observations,* which, together with his examinations† of material, form the basis of the discussion.

The work has been carried on in the Stratigraphic Laboratory at Columbia University, and was undertaken at the suggestion of Professor Grabau, in whose classes the researches have been discussed and to whom the writer is indebted for many suggestions.

The Saint Peter sandstone has often been described in admirable detail.‡ To this feature the present writer has added little. To the comparative side and the resulting interpretation as to conditions prevailing during the time represented by this formation this discussion of what is otherwise so well worn a subject is directed. If the conclusions are well founded, then they explain the problem of origin also; and its uniformity of grain, its purity of composition, its great extent, its apparent conformity to adjacent beds are not inexplicable sedimentary puzzles.

From the nature of the undertaking, it will be necessary to summarize the essential points of the facts gathered from observers touching this formation and later to compare and interpret local variations.

Since finishing the manuscript of this article§ the writer's attention has been called to a paper by A. Rutot, which contains a very suggestive discussion of the principles involved in sedimentation, and includes the same ideas and general treatment that are here applied to a particular case.

General Character and Distribution of the Sandstone

The Saint Peter formation is a quartz sandstone, a silicarenyte. In most descriptions the same characteristic are enumerated. It is coarse and uniform grained, with almost no cementing material and little im-

* These consist of field observations for many years in the Upper Mississippi Valley region.

† Recent laboratory study of material obtained from localities distributed throughout the areal extent of the formation.

‡ To attempt a complete acknowledgment of the sources of information on this subject is scarcely practicable. They are exceedingly numerous. The chief publications relied on, however, are those of the Geological and Natural History Survey of Wisconsin, the Geological and Natural History Survey of Minnesota, the Geological Survey of Iowa, the Geological Survey of Missouri, the Geological Survey of Illinois, the Geological Survey of Michigan, including descriptions and discussions by T. C. Chamberlin, N. H. Winchell, W. H. Norton, C. R. Keyes, Samuel Calvin, James Hall, J. D. Whitney, A. H. Worthen, James Shaw, F. L. Nason, and others. Among authors of important special papers or reports are D. D. Owen, Joseph F. James, C. W. Hall, F. W. Sardeson. Citations are made to many of these at appropriate points throughout the paper and especially in those matters with which the present discussion is mainly concerned.

§ A. Rutot: Les Phénoménes de la Sedimentation Marine. Bull. Musée Royal d'Histoire Naturelle de Belgique, T. ii, 41-83, 1883.

‖ Journal of the Cincinnati Society of Natural History, July, 1894, p. 120. The St Peter's Sandstone, by Joseph F. James.

purity. At most typical localities the composition is about 99 per cent SiO_2. In color there is considerable variation, locally, chiefly due to iron stains, but at the typical exposures it is white or yellowish, often only faintly streaked with color.

Usually the rock is massive, with only occasional bedding planes or color zones or other structural features.

This formation, considering its exceptional character, has very wide distribution. Its outcrops occur along a zone including southeastern

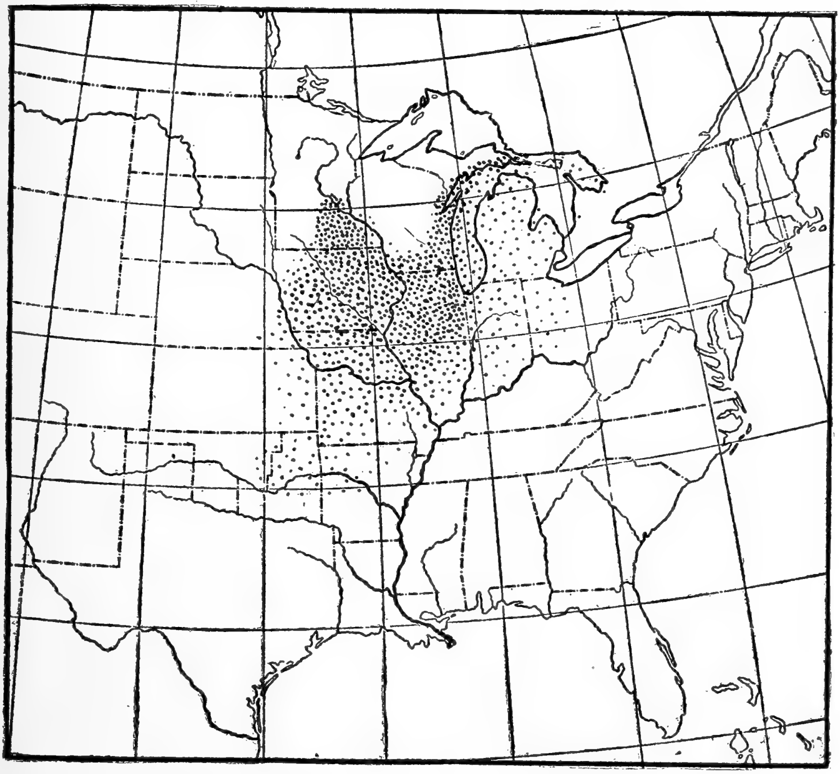

FIGURE 1.—*Areal Distribution of the Saint Peter Sandstone Formation*

Minnesota to the vicinity of Minneapolis and Saint Paul, southwestern and southern Wisconsin and a narrow fringe along the eastern margin of that state; a like strip across the northern peninsula of Michigan, passing into southern Canada in the vicinity of Saint Joseph island, continuing in an easterly course. It has a most typical development in northern Illinois and portions of eastern Iowa. There are also outcrops of the same formation in Missouri.

From the distribution of the outcrops, together with the records of deep wells and local stratigraphic interpretation, it is certain that the Sain Peter area includes almost the whole of Iowa, Illinois, and Missouri, together with large areas in Minnesota, Wisconsin, Michigan, and Indiana, as well as less clearly defined portions of Nebraska, Kansas, Arkansas, Indian Territory, and possibly North Dakota. The northerly border of this great tract exhibits the upturned eroded edge of the Saint Peter in characteristic facies. The southerly and easterly border, on the other hand, passes more and more deeply beneath later sediments, beyond observation except by deep well records. These indicate, however, a gradual increase of argillaceous and calcareous matter in this direction. The distribution and boundaries are plotted on the accompanying outline map.

General stratigraphic Position

The Saint Peter is Ordovicic in age. In its northerly exposures it is overlain by a limestone that is correlated with the Stones River formation by Ulrich and Winchell,* and it is underlain by a dolomite, called the Shakopee, also Ordovicic in age, but of doubtful equivalence. The descending series of dolomites, shales, and sandstones beginning with the Shakopee, known as the "Magnesian series,"† carries somewhere the line dividing Cambric from Ordovicic time, but the exact position of it is uncertain. The base of the Paleozoic column is represented by a thick sandstone and conglomerate, commonly referred to as the Potsdam or the Basal sandstone, or the Saint Croix formation, by workers in different fields.

The Saint Peter therefore occupies a position well toward the base of the Ordovicic series, and it is the uppermost one of the five sandstone formations which give a predominant arenaceous character to the basal Paleozoic rocks of the northern Mississippi Valley region. This relationship is indicated in figure 2.

In other areas, especially southward, there may be conditions of overlap that modify minor stratigraphic relationships of succession, as will be indicated in another paragraph.

It has been common usage to correlate the Saint Peter with the Calciferous (Beekmantown) or with the Chazy of New York. This has been done more on the order of succession and similarity of rock type than any direct evidence. The few fossil forms found give little help in exact correlation.

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* Geol. and Nat. Hist. Survey of Minnesota, Final Report, vol. iii, part ii, pp. xciii-xciv.
† Bull. Geol. Soc. Am., vol. 6, pp. 167-198.

Lithologic similarity in widely separated areas is a most questionable basis for correlation or time equivalence.

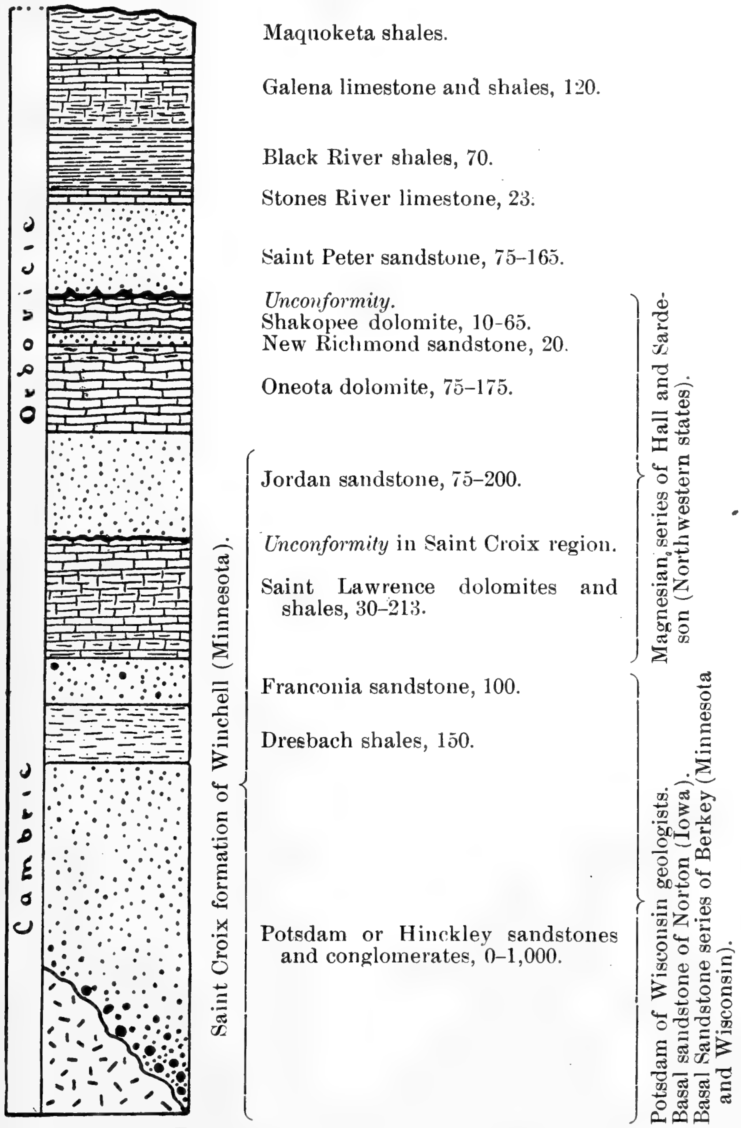


FIGURE 2.—*Lower Paleozoic Formations.*

Upper Mississippi Valley region. Relative thickness of members of the series is that of southern Minnesota.

Besides, in this case, even if the beds could be followed continuously from west to east, a former land barrier seems to have actually separated

the two seas in which the typical formations were accumulating. This still further increases the difficulty of direct comparison and makes any statement of exact correlation in terms of Chazy or Calciferous (Beekmantown) of doubtful value. The only method left is by the indirect process of comparing the succession from a well established base of uniformly recognized formation.

The formation best suited to this datum-plane use is the Black River beds. They have a more universal extent than any other of the lower members of the series, in that they cross the New York divide (Frontenac axis) and are recognizable in both ancient seas.

On the east side of the divide, in the ancient sea that occupied New England and the eastern borders of New York, was laid down a continuous series whose succession is as follows:

	Feet
Black River	80
Chazy *	800
Beekmantown	1,500
Potsdam	0-1,000

On the west side of the divide the Chazy and Beekmantown are not at all or only partially developed. Their time equivalents are represented in the formations and erosion intervals preceding the Black River beds, as they overlap against the flank of the Adirondacks. The first one of these below the Black River is the Lowville, resting on the basal conglomerate and Archean gneiss of the protaxis on the west side of the Adirondacks. In the Mohawk valley some 400 or 500 feet of Beekmantown rest on the pre-Cambric gneiss, followed after a pronounced erosion interval by a few feet of the upper Lowville, which grade into the Black River. As shown by well borings, successive members of the very extensive series of lower Ordovicic and Cambric sediments appear one below another at greater and greater distance from the crystallines. Toward the southwest there are prevailingly limestones and dolomites, constituting the Stones River group and Knox dolomite, which together attain a great thickness.

In the interior sea, the so-called Mississippian sea, there is a close relationship of formations. There is, however, much variety in the series along the margins, and the numerous breaks and oscillations make it possible locally to subdivide minutely with success. In the deeper, less disturbed, sea basin there was apparently continuous sedimentation and a fairly uniform type of deposit resulted. Into this each marginal type

* Brainard and Seeley: Bull. Am. Mus. Nat. Hist., vol. viii, p. 305.
American Geologist, vol. ii, p. 323.
Brainard: Bull. Geol. Soc. Am., vol 2, p. 293.

shades by gradual merging of character and each break or interval terminates in wedge-like form.

In this Paleozoic interior basin the Mississippian sea of Cambric time advanced slowly from the southward and in its marginal encroachment spread out the great basal conglomerate and sandstone series that is so prominent in the Upper Mississippi valley and the Great Lake region, where it is of Upper Cambric to Lower Ordovicic age. With successive oscillations of level, and accompanying variation in character and supply of sediment, the whole series accumulated. They are largely sandstones near the base and prevailingly limestones at higher levels and at greater distances from shore; but almost without exception the margin was everywhere gravel and sand—a continually advancing sheet of conglomerate and sandstone, growing younger step by step with the northward advance, a continuous lithologic formation, but, in its successive stages, of very unlike time equivalence. It probably ranged from lowest Cambric

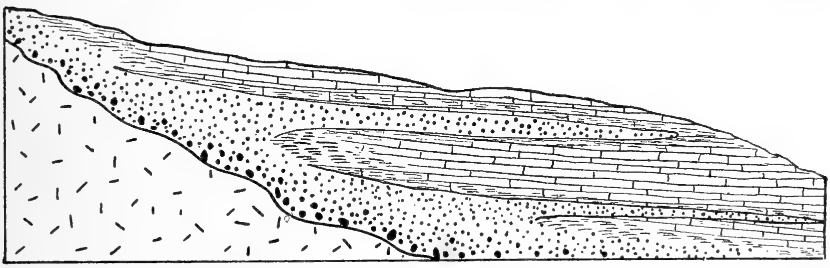


FIGURE 3.—*Generalized Sketch illustrating Relationship of interbedded Sandstones to great Basal Sandstone Formation.*

in the southern United States continuously to and including the Saint Peter of the Ordovicic on its original margins.

With each recurring period of elevation of the land, or retreat of the sea, or excessive waste supply, the sands crept seaward over the deeper sea types of deposit; and with each subsidence and consequent advance of the sea the sand was left behind as a continuous bed, to be covered in large part by other sediments. Naturally enough the nearer to the margin of the sea a locality is the greater prevalence of sand is to be noted in its series of formations, and, other things being equal, the greater the number and the greater the thickness of the interbedded wedge-like sandstone formations.

The Saint Peter is the fifth and last one of these sandstone formations in the Upper Mississippi valley.

Of great significance is the comparative thickness of the involved formations in different parts of the region. In this discussion the formations both above and below the Saint Peter must be included.

Ulrich and Winchell* correlate the 300 to 400 feet of Stones River limestones and shales of Kentucky and Tennessee with the 23 feet of limestone just above the Saint Peter in Minnesota, remarking that the Minnesota organic forms are most like those of the uppermost member of the Stones River of Kentucky.

Part of the Knox dolomite of Tennessee below the Stones River group is also credited to the Ordovicic; how much should be is not known; but this much is clear, that in the Kentucky-Tennessee area there was continuous marine deposition, chiefly of a limestone character, amounting to probably 1,000 or 1,500 feet, during the time from the close of the Cambric to the end of Stones River time—a period marked in the northwest by the deposition of 75 to 150 feet of shaly limestones and dolomites and 150 feet of sandstone, within which there is at least one break of some significance.

Only the upper representatives of the Stones River group also are to be seen in western New York, where the Lowville overlaps against the earlier formations, as noted by Ulrich.

Broadhead† calls attention to the interpolation of 80 to 190 feet of the Missouri survey's "First Magnesian" between the Saint Peter and the "Trenton limestone." This formation does not appear at all in the northernmost areas, and, while the underlying magnesian formation has a thickness in Missouri of 150 to 230 feet, in Minnesota or Wisconsin it seldom reaches 75 feet. It appears therefore that the formations thicken considerably southward.

The Shakopee below the Saint Peter is correlated with the Calciferous (Beekmantown) of New York by Sardeson.‡

The same author has described the fossils§ found in the Saint Peter

* Geol. and Nat. Hist. Survey of Minnesota, Final Report, vol. iii, part ii, introduction.

† American Geologist, vol. 34, no. 2, August, 1904.

‡ Bull. Minn. Acad. Nat. Sci., vol. iv, no 1, p. 104.

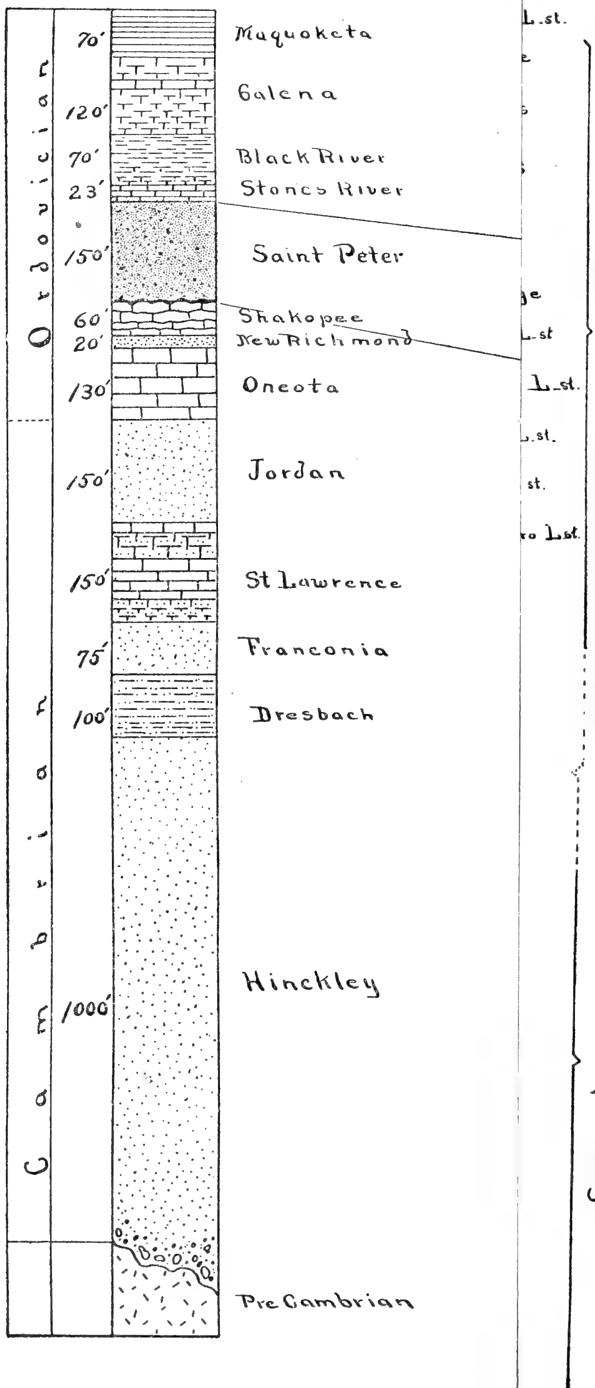
§ There are marine fossils in the upper part of the Saint Peter at Saint Paul, Minnesota. These have been described by Sardeson in Bull. Minn. Acad. of Nat. Sci., vol. iii., no. 3, and vol. iv, no. 1, p. 79. The following genera are represented: *Cypricardites*, 4 species; *Modiolopsis*, 5 species; *Tellinomya*, 2 species; *Holopea*, 2 species; *Murchisonia*, 2 species; *Ophileta, Platyceras*, and *Pleurotomaria*, 1 species each; *Orthoceras*, 3 species, and one species each of *Crania, Lingula, Orthis, Ptylodictya*, and *Rauffella*.

There were found at this place 28 species. Although nearly all described as new species, they are as a whole very like the forms occurring in the overlying limestone. Other localities have furnished a few forms. At Ripon, Wisconsin, in transition beds, *Orthoceras* is found. Except fucoidal markings and *Scolithus Minnesotensis* James, there are no others reported from Wisconsin.

Winchell reports *Scolithus* from Faribault, Minnesota, probably the same as *S. Minnesotensis* James. (The Saint Peter Sandstone, Cin. Soc. Nat. Hist. Jour., 1894, p. 134.) At Fountain, Minnesota, in transition beds to Stones River above, not in typical Saint Peter, *Lingulepsis morsensis* Winchell and an *Orthis* resembling *O. testudinaria*. *Planolites* is also reported from Minnesota.

Meek refers to a *Murchisonia* and a crinoid column from Monteau county, Missouri; Shumard reports a *Straporollus* and a *Chemnitzia* from Ozark county, Missouri, and an *Orthoceras* is recorded from Maries county, Missouri.

MINNESOTA.



Representing the series of sandstones characteris ords.

near Saint Paul, Minnesota, and concludes from them that this formation is much more nearly allied to the overlying Stones River than to Shakopee below. This is in accord with the existence of a break between the Shakopee and the Saint Peter, indicated both by the unconformity between them and the cessation of sedimentation that has resulted in thinner beds on this margin.

Therefore the uppermost Saint Peter, especially in its northern margin, is Stones River in age; but the whole formation is involved in a retreat and advance of the sea over the area, and has, as is usual in sandstones, no perfect time unity in its whole extent; and the break, except where it has imprinted erosion features on the underlying Shakopee, is swallowed up in the sands of the deposit.

A few columns drawn to scale (see plate 24), with the lines of the formations indicated, will serve to better show the relationship.

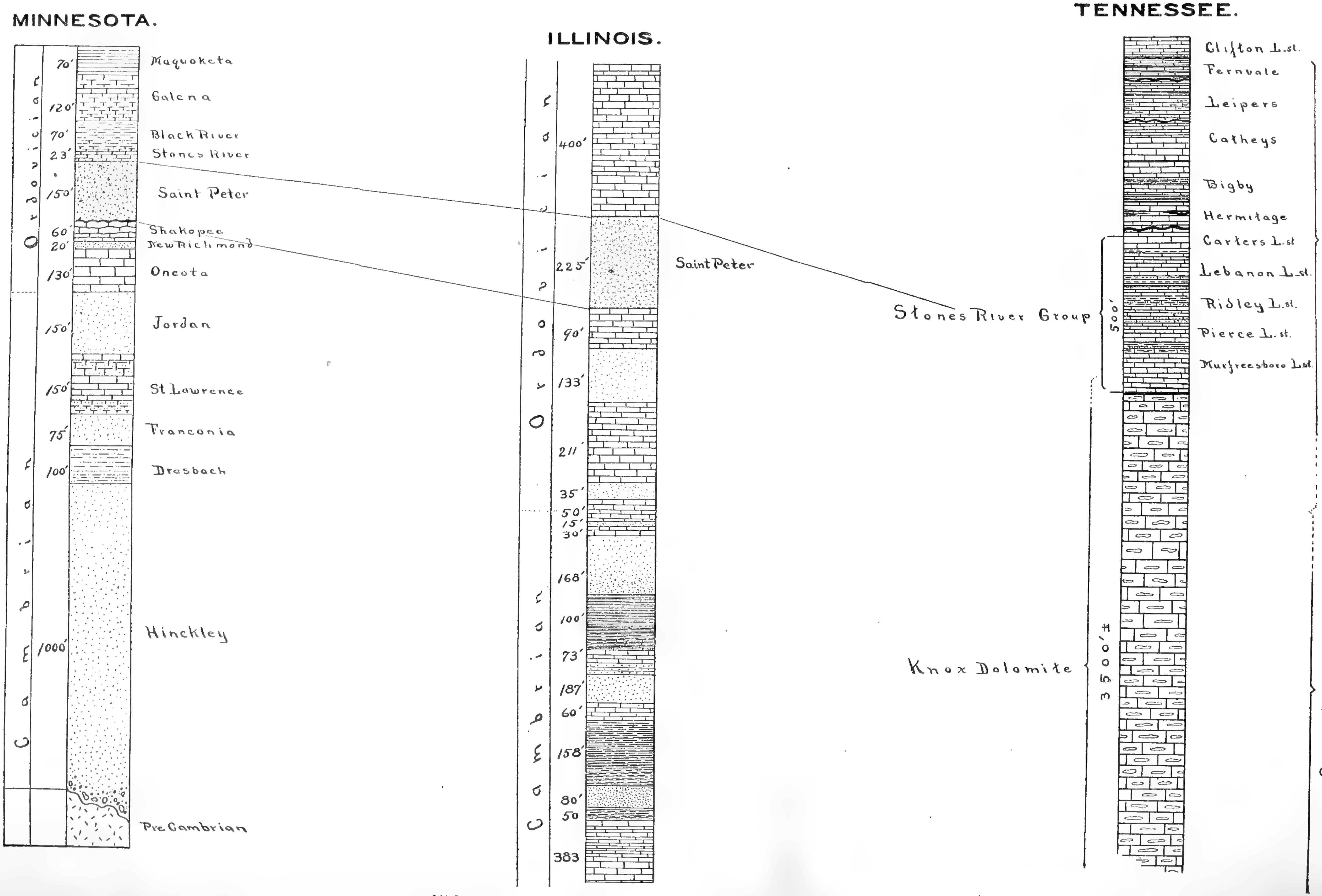
Origin suggested by Writers

There have been many different theories as to the origin of the Saint Peter sands and their present purity. Its extreme purity and great extent seem to have made ordinary sedimentation processes appear insufficient to many observers. In accord with this idea, several early writers have suggested* chemical precipitation as a probable origin. Most observers, however, have agreed to the mechanical character of the deposit and have suggested a variety of subordinate agencies.

James Shaw, in the geological reports of Illinois, at one time advocated the wind as the effective agent in producing the cross-lamination and ripple-like marks, but later seems to have abandoned this idea. Norton of Iowa also suggests the wind as a probable factor. Owen and many others seem never to have considered any modification of the ordinary sedimentary origin necessary. Sardeson,† on the other hand, while maintaining the sedimentary origin, considers the unusual purity due chiefly to the porosity of the rock, favoring free circulation of underground water and the consequent leaching out in solution of all constituents except the quartz grains.

Any more definite statement than that the Saint Peter owes its existence and character to the usual processes of sedimentation depends for support more on the variability of character than upon its reputed con-

* Keating, Hall and Whitney, Winchell.
† Sardeson: Bull. Minn. Acad. Nat. Sci., vol. iv, no. 1, 1896, p. 86.



CAMBRIC AND ORDOVICIC SERIES IN SOUTHERN MINNESOTA, ILLINOIS, AND TENNESSEE

Representing the series of sandstones characteristic of the Northern region, the comparatively uniform succession of dolomites in the South, and the intermediate equivalents. The Illinois section is from well records.

stancy. The views of the writer as to origin are necessarily involved in a discussion of these lines of evidence.

Variability of the Saint Peter

VARIATION MORE PROMINENT IN MINOR DETAILS

A minute study makes it clear that the reported constancy of this formation is somewhat overdrawn. In the broader characteristics of sandstone formations, it is fairly constant, but in minor detail it is very variable, and these usually neglected variations, it is thought, are in this case a key to the bit of history that the Saint Peter represents.

THICKNESS

This formation varies in thickness from a mere film, a layer of sand grains, as in certain cases in eastern Wisconsin, to 225 feet in Illinois.* It occasionally exhibits a range of from 1 foot to 100 feet within so short a distance as a quarter of a mile.†

This rapid change is described as due to the undulating magnesian limestone floor. The normal thickness in Iowa is about 100 feet, and this may be taken as a fair estimate of its average thickness over the greater part of the whole region of its distribution.

PURITY

Although more than 99 per cent pure quartz in some localities, this condition is by no means universal. An analysis given by Hall and Sardeson shows for the fossiliferous rock occurring at South Saint Paul:‡

SiO_2	99.75 per cent
Fe_2O_3	Trace
MgO	Trace

A Minneapolis sample gave 98.50 per cent of SiO_2.

The saccharoidal sandstone (Saint Peter) of eastern Missouri, in the vicinity of Saint Louis, so important for many years past in the glass industry, is also remarkably pure. It is given as more than 99 per cent SiO_2.

The Saint Peter, however, is not always free from clastic impurity. Hall and Sardeson note the presence of fine white kaolin in the Saint Anthony area.

* Geological Survey of Illinois, vol. vii, p. 49.
† T. C. Chamberlin: Geology of Wisconsin, vol. ii, 1887, pp. 285-286.
‡ Bull. Geol. Soc. Am., vol. 3, p. 351.

There are shale intermixtures at Boone, Iowa, calcareous and shale intermixtures in Wisconsin, and iron oxide heavily developed in a few places. The formation in Missouri, Indiana, Ohio, and Kentucky carries a marked percentage of lime and argillaceous matter in contrast with the average northern outcrops.

Specimens at hand from La Salle county, Illinois, show a considerable percentage of earthy impurity, while one from Wisconsin, probably a transition phase, is very heavily charged with carbonates, though on the whole the Saint Peter is a remarkably pure sandstone formation. Its greatest variability is marginal and throws some light on the question of origin and conditions prevailing during its accumulation. This variability, however, is markedly different along opposite margins—that is, the landward as opposed to the seaward side—and is well within the range of characters in every respect that one should expect. Thus on the northern margin there are developed occasionally breccias and marginal conglomerates and various foreign intermixtures, while far southward the Saint Peter and its equivalents become shaly sandstones, calcareous shales, and even siliceous limestones.*

BINDING

Throughout most of its extent the individual grains of the Saint Peter have almost no binding. At Minneapolis a freshly exposed fragment may be crushed in the hand or its grains readily rubbed off by the fingers. In all cases exposure increases the strength of the bond, so that occasionally it has been made use of in light structures. In Ogle county, Illinois,† it is recorded that the outcrops, although apparently of so friable material, resist weathering with great success.

Occasionally in other localities there is strong lime or iron oxide binding, while local induration to a quartzite is less common. A sample from Missouri sent by the kindness of Dr E. M. Buckley exhibits secondary growth of almost every grain, the pyramidal faces being especially sharply developed and occasionally developing almost a complete doubly terminated quartz crystal; yet the rock is not well cemented; it is not much more firm and resistant than the average specimen.

In all cases there is either a striking lack of cementation or if well developed it is extremely local. The places where iron oxide is infil-

* Marginal character may have prevailed also in Pennsylvania and West Virginia, as well as along some continental border in the west, but if so the type of rock is different and is not recognized as Saint Peter.

† James Shaw: Geology of Illinois, vol. v, p. 116.

trated furnish some firmly bound rock, but this is in irregular bands rather than a general constituent.

STRUCTURE

In many places the rock is massive, with but faint traces of bedding or any other marking. At still others the bedding planes are strongly marked and the beds comparatively thin, passing in numerous places into shaly facies. Often there is cross-bedding, as noted particularly in northern Illinois, with ripple marks well developed. These irregularities are still further accentuated by color streaking. Variations are much more notable in the central portion of the Saint Peter area than on its margins, although they are not wholly lacking along the northern margin. Chamberlin* refers to structures typical of ebb and flow and ripple marks in Wisconsin.

Nearly all the strong coloring described in the Saint Peter is confined to structural inequalities, mostly bedding or cross-bedding lines. In so porous a rock of so simple composition one would not expect enough selective capacity to connect the color streakings with late infiltration. Even the coloring seems to point back to the conditions under which the rock accumulated.

Transition

There are occasionally brecciated and conglomeritic Lower Magnesian fragments in the marginal facies of the rock in eastern Wisconsin and northern Michigan. Uusually the transition from Magnesian dolomite to Saint Peter and from Saint Peter to Stones River limestone again is abrupt, but even this is not universal, sand mixed with calcareous matter or clay mixed with the sand being an occasional variation.

The overlying limestones and shales of the Stones River group at all places are described as perfectly comformable to the Saint Peter.

Unconformity

The underlying dolomite and the succeeding Saint Peter are frequently unconformable. This condition has been described in Michigan, Wisconsin, Iowa, and Missouri, where occasionally the dolomite floor is very uneven. In places the dolomite floor is so hummocky as to project up through the whole thickness of the Saint Peter, so that the sandstone only fills the hollows and valleys.

In generalizing the isolated descriptions it appears that the greater

* Geology of Wisconsin, vol. i, p. 146.

conformity as a rule obtains at the greater distance from the continental land margin of ancient Laurentia. In Missouri, according to Winslow, there is an unconformity below the saccharoidal sandstone, now correlated with Saint Peter, and erosion valleys have been described there.*

Throughout the greater part of the region of the Saint Peter the lower contact is not within surface observation, so that, even if unconformity were general, most descriptions would necessarily fail to note it.

In a few isolated areas where the original landward margins are still preserved, or where ancient islands project through, the Saint Peter seems to merge into the Basal sandstone, Potsdam, either by thinning out of the Magnesian series or by its destruction and overlap, so that the break is swallowed up in the uniform textured sandstone formation.

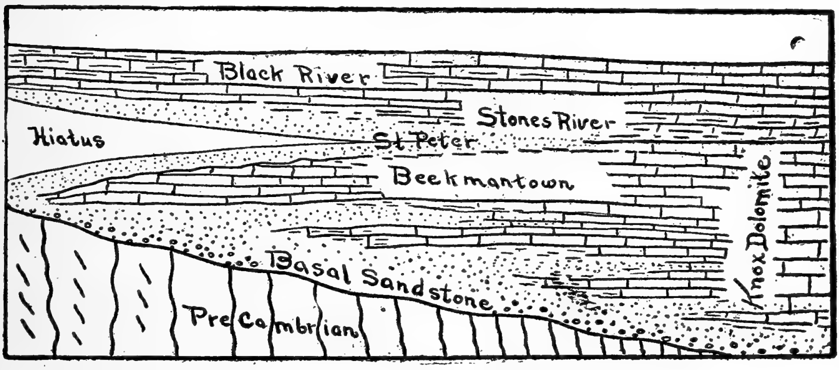


FIGURE 4.—*Stratigraphic Range of the basal Sandstone.*

This generalized sketch indicates the relationships of the Saint Peter formation to the larger groups representing deep-sea deposits, and illustrating the conception of an erosion interval in Saint Peter time.

This relationship is well shown and fully discussed in the Geological Survey reports of Wisconsin.

When the evidence of unconformity is lacking there may nevertheless have been dry land at so nearly baselevel position that erosional forces were largely spent upon the loose mantle of shifting sands left by the outwash of the retreated sea. Here and there conditions were such as to permit penetration of this mantle and imprint the marks of an erosion interval on the undulating Shakopee. It is the writer's opinion that the Saint Peter sandstone is of such composition as to permit obliteration within itself of all marks of such an interval. This is probably true of all coarse grained or very pure sandstone formations. Great interbedded sandstones as a type doubtless represent periods of marked oscillations of

* Missouri Geological Survey, vol. vi, p. 357.

level, with retreat of the sea, an erosion interval, a readvance of the sea, each with its characteristic deposits. Just as in displacements by folding or faulting, such disturbances are dissipated by ready adjustments among the easily shifted grains, so that occasionally all traces of the movements are wholly obliterated, so in like manner may an erosion interval be swallowed up and almost wholly lost in the shifting and worked over sands that finally constitute the formation. It may easily happen that sands spread out by a retreating sea should be wholly worked over by the readvance, and yet, on a very uniform surface, leave no trace except a rather abrupt transition. In such a case the underlying bed would carry most of the marks preserved at all and might exhibit prominent erosional unconformity in limited areas. The overlying bed, in this instance the Stones River limestone, should be perfectly conformable, as descriptions show it to be (see figure 4).

Breccias are developed to a limited extent at some of the Saint Peter-Shakopee contacts, according to the records of both the Wisconsin and the Michigan reports. The Magnesian is represented as wedging out in an enveloping upper and lower sandstone wherever an original margin is preserved.

In Michigan this edge is the remnant of a bed partly destroyed by the encroaching Saint Peter sea, as at one time interpreted by Rominger, and beyond its present margin the Saint Peter should be expected to merge into the Great Basal sandstone ("Eastern sandstone") of the region. This interpretation, and indeed the presence of Saint Peter in Michigan at all, seems to have been regarded with doubt by many writers; yet there is no inconsistency about the occurrence in any respect, and the later state reports* under Doctor Lane add to the Saint Peter data. It is probable that the same type of edge was developed along the whole length of the ancient shoreline. In the extensive denudation of the region, however, this, together with all later deposits, has been destroyed except in the most protected localities.

In short, it is held that in the case of the Saint Peter evidence gathered from a study of its extent as well as its contacts and transitions is in support of a considerable erosion interval.

Source of Supply of Material

The Saint Peter sands are widely and rather evenly spread. Considering the possible sources of supply, they are carried to surprising distances. There is no doubt at all of the sedimentary character of the

* Geological Survey of Michigan, Annual Reports for 1901 and 1903.

rock; but for such a deposit all the sources in this case are marginal, except perhaps locally in Missouri; and of all the margins only the northern one seems to fulfill the conditions of a coastal supply. Along this northern coast there was at all times a broad and thick accumulation of sands from the waste of the continent. It lapped against the retreating shore in such position and in such condition that any considerable diastrophic movement elevating the land would subject great quantities of this loose material to the outwash of the sea and other transporting agencies. Any differential movement along this region might also subject underlying strata to erosion along the margin to the extent of destroying them, as is represented by Rominger in northern Michigan. Likewise any orographic movement or displacement by faulting, resulting in the elevation of any considerable portion of the subcoastal margin, would still further augment the supply of these sands for seaward transportation.

In this connection it is recalled that there is extensive displacement by faulting within the area of the basal sandstones—Eastern and Western sandstones—of the Lake Superior margin. These movements were at least subsequent to the deposition of the chief mass of these formations, since the beds still remaining are much affected along this fault zone.*

It is not clear what time this faulting took place, but certain field relationships suggest that the displacement may have begun before the Lake Superior sandstones, as we now have them, were completed. At any rate, the raised blocks must have been capable of furnishing considerable excess of sand over regular erosion sources and must have resulted in some extension of the sand sediments seaward. The Saint Peter is the last of these sand extensions and certainly owes its existence to one or another of these dynamic factors, perhaps to all of them.

In the areas of no faulting in eastern Wisconsin the "Potsdam" thins out northeastward, according to the Wisconsin geologists, not by general thinning of all the beds, but by suppression of the lower members. It is worth while to note that this would not be true under normal conditions, except so far as overlap prevailed, and in case of retreat and advance with destruction of underlying beds.

To this phase of the problem the present condition of the underlying Shakopee dolomite adds evidence. The Saint Peter lies on the billowy surface of the Magnesian limestone, filling up its troughs and in most cases surmounting its prominences. In given instances 54 and 82 and 100 feet of sandstone was observed in these troughs, while adjacent knolls of magnesian dolomite had scarcely more than a film of sand to mark

* U. S. Grant: Bulletin vi, Geol. Survey, Wisconsin, p. 17.

the separation* of this formation from the overlying Trenton (Stones River). This irregularity is greatest from Dodge county northward. In Missouri an inequality of this type is credited to actual stream erosion.

Few localities exhibit the Shakopee-Saint Peter contact well enough to furnish reliable data for most of the field. Hall and Sardeson have described this contact in Minnesota, also as uneven as a rule, but have considered it chiefly due to folding,† which dies out upward in the Saint Peter. The overlying Trenton (Stones River) is not affected. It seems well supported then, by combining the observations of all these men in their particular fields, that Saint Peter time was one of some considerable dynamic disturbance, that it resulted in both folding and faulting of the preceding series locally, and, in the region as a whole, was accompanied by diastrophic movements by which much of the Upper Mississippi valley and Great Lake regions became dry land for a part of the time.

Some characters of the formation (noted briefly under the heading of "Variability of the Saint Peter") bear on this problem and suggest further modification of the general interpretation.

Structural Character and Texture

A study of the texture of the Saint Peter made on specimens‡ gathered from localities of wide areal range furnishes a few suggestive facts.

Microscopic examination shows that in typical Saint Peter there is a total absence of large grains that are usually classed as gravel, and almost as complete absence of extremely fine grains, such as fall within the class of dust. In this respect there is no very marked difference among the various samples. The sands from La Salle, Illinois, and one sample from Wisconsin show most impurity.

The range of sizes runs from 1 millimeter down to .01 millimeter in a few cases, but the bulk of the rock is made up of grains from .4 millimeter to .05 millimeter in diameter.

The diameter of grains in samples examined from typical localities range prevailingly from .05 millimeter to .6 millimeter, an average for by far the greatest number of grains being from .1 to .2 millimeter. So far as different parts of the area or different horizons in the formation have been subjected to scrutiny, there is not any great variation. Hall and Sardeson, however, note that there is considerable diversity of texture

* Geology of Wisconsin, vol. ii, 1877, pp. 285-286.

† Bull. Geol. Soc. Am., vol. 3, p. 353.

‡ For most of this material I am indebted to Dr E. M. Buckley, of Missouri; Superintendent Thomas J. McCormick, of La Salle, Illinois; Professor Ira A. Williams, of Ames, Iowa, and Professor C. K. Leith, of Wisconsin.

in Minnesota, Olmstead, and Fillmore counties, in the southern part of the state, exhibiting much coarser grain than the Minneapolis-Saint Paul area. They also remark a noticeably coarser development at the base* of the formation at Cannon Falls and Northfield.

Under the microscope, grains from the Saint Paul area vary from .05 to 2 millimeters in diameter. Of these the larger grains are all much worn and as a rule very perfectly rounded, while the smaller, .1 millimeter and less, are strikingly more angular. This same relationship is shown by the samples from Missouri, where, however, the grains range as high as .6 millimeter in diameter and a greater proportion of them are well rounded. The Illinois rock is described as composed† of very uniform small round grains, as seen under the microscope. Specimens examined from La Salle county show more than the average impurity of iron and clay and fine matter.

Southern Wisconsin has a similar record. In Michigan the narrow strip through the upper peninsula that has been correlated with this formation‡ is made up of the grains that are described as angular and associated in places with fragments of the preceding and destroyed edge of the magnesian.

Two samples from Iowa sent by Ira A. Williams, of Iowa State College, show the greatest range of any received. Both are from the eastern border of the state. In one the grains are nearly all large, some exceeding 1 millimeter, and all are rounded and beautifully pitted. The other is very fine grained, chiefly .05 to .1 millimeter in diameter, and also well worn. Both are very pure.

Only the larger grains in most of the samples are well rounded. Those of .1 millimeter and over are all much worn. Commonly the smaller grains, .05 millimeter and less in diameter, are strikingly more angular. In only one case, an Iowa sample of very fine grain, are all grains worn. In one sample from Missouri, although the grains show marked secondary enlargement, the original character does not depart from the average type.

The worn grains in all the samples are beautifully pitted in the manner so often seen on wind-worn fragments. The agreement of the textural character of this rock with the requirements of a wind transported deposit is at once apparent. Every grain yet observed by the writer from this formation falls within the range of wind competence. According to the researches of J. A. Udden, grains comparable to those of largest

* Bull. Geol. Soc. Am., vol. 3, p. 351.
† Geological Survey of Illinois, vol. v, p. 116.
‡ Geology of Michigan, vol. I, pt. iii, pp. 56, 64, 72.

size in the Saint Peter, those most rounded, as noted above, would not be picked up and carried far by the wind, but could easily be rolled along the ground. The smaller sizes abundant in the rock fall within the lifting capacity of the wind and might be carried long distances.* These smaller sizes are prevailingly less worn and more angular than the larger sizes, and this again is consistent with such agency. Of all agents of transportation, wind is the best assorter. From a given supply of sand of reasonable areal limits the wind is able to remove the finer dust very perfectly. The finest and the coarsest particles are widely separated. If, therefore, the supply area is not so large as to outreach the assorting competence of prevailing winds, and if the winds involved are not so changeable as to undo one day what may have been accomplished on the previous one, the result is sure to be a perfectly cleaned sand.

Conclusions as to Origin

The writer is well aware of the incompleteness of an argument of this kind. To find that certain phenomena are consistent with a certain explanation is far from proving its correctness; but, in view of the difficulty acknowledged by workers in the Saint Peter, it is at least worth noting that wind agency will account for the purity and textural character of this formation under very reasonable conditions.

The surface over which the Saint Peter sands were deposited was apparently very uniform. If it had departed far from a low-lying plain, we should doubtless have many marks of it in erosion forms characteristic of such elevation. On that plain, on its retreat, the sea spread great quantities of sand and left the marginal supply (Basal sandstone margin) exposed to all the transporting agencies. This the wind began to carry as dune sands along the shore. Into these sands the rivers sank as they coursed toward the retreating sea, accomplishing little in erosion. At the maximum retreat of the sea, it is the writer's belief that the Saint Peter sands presented the aspect of a shifting-sand plain, perhaps akin to a desert in this one feature at least, though not necessarily arid; so the sands were washed out by the retreat of the sea and thereby assorted, then worked many times over by the wind in the absence of the sea, and thereby still more perfectly assorted, and finally, in the readvance of the sea, much of it was again worked over a last time, thereby reaching its present remarkable condition of purity.

The Saint Peter therefore owes its constancy of grain and its purity

* J. A. Udden: The mechanical composition of wind deposits, Augustana Library Publications, No. 1, 1898.

of composition, in the writer's opinion, not to chemical precipitation of the rock, not to subsequent leaching, but rather to the unusual completeness of the assorting process accomplished by wind and water on a sand largely derived from a previous sandstone formation. The marks of water action and sedimentation are too numerous to admit the chemical theory for an instant. As for subsequent removal by leaching, the results are too capricious for so general a cause. It has not removed the color stains that so commonly emphasize the structural features. It is impossible that nearly all the mineral dust, even that of the quartz type, should be removed by such agency and yet not attack the larger grains, even enough to destroy their wind-worn finish or the stains they carry. Such carbonate matter as accumulated in the sands has been removed largely, it is true, but there is no evidence of any considerable quantity of it ever having been present. For the removal of siliceous matter there is no evidence.

That the Saint Peter sandstone was deposited in water and preserves chiefly such structures as are common to sediments is certain; that its grains fall within the range of wind transportation and show characteristic wind-worn surfaces is equally clear; that the formation relationships argue an extensive retreat of the sea and an erosion interval is well supported—these factors alone are sufficient to account for all the peculiarities and remarkable characters of the Saint Peter, without any special agency.

Physiographic Changes

A reasonable interpretation of the foregoing facts and observations suggests the following outline of the physiographic changes of the time:

1. Just preceding the Saint Peter epoch the sea stood far in on the continental areas represented by Laurentia at the north and Appalachia at the east. These were connected by an isthmus occupying the position of the Frontenac axis. To the eastward lay the Atlantic ocean and the gulf of Maine, in which the typical Beekmantown sediments were already accumulating. To the westward, in the great Mississippian sea, dolomites and limestones of the Magnesian series and their equivalents were being deposited.

2. With a reversal of epeirogenic movement the sea began to retreat. There were some marginal disturbances, perhaps both folding and faulting, by which arose subsequently some structural unconformity and through which possibly extra supplies of sands were made available.

3. At maximum retreat, judged by the distances to which heavy sands were carried, the whole upper Mississippi valley became dry land; it

became a waste of drifting sands; but a deep bay extended northward to the southern boundary of New York, as appears from records of undisturbed sedimentation in Center county, Pennsylvania.

4. A readvance of the sea northward to the vicinity of its original position followed. In this movement the sands that had been dragged out by the retreating sea and carried out by streams or transported in large part by winds were worked over, given their characteristic structures, and such fossils as belong to the formation were buried in them. The natural break representing the time interval, that would have been preserved in almost any other type of rock, is largely obliterated. With

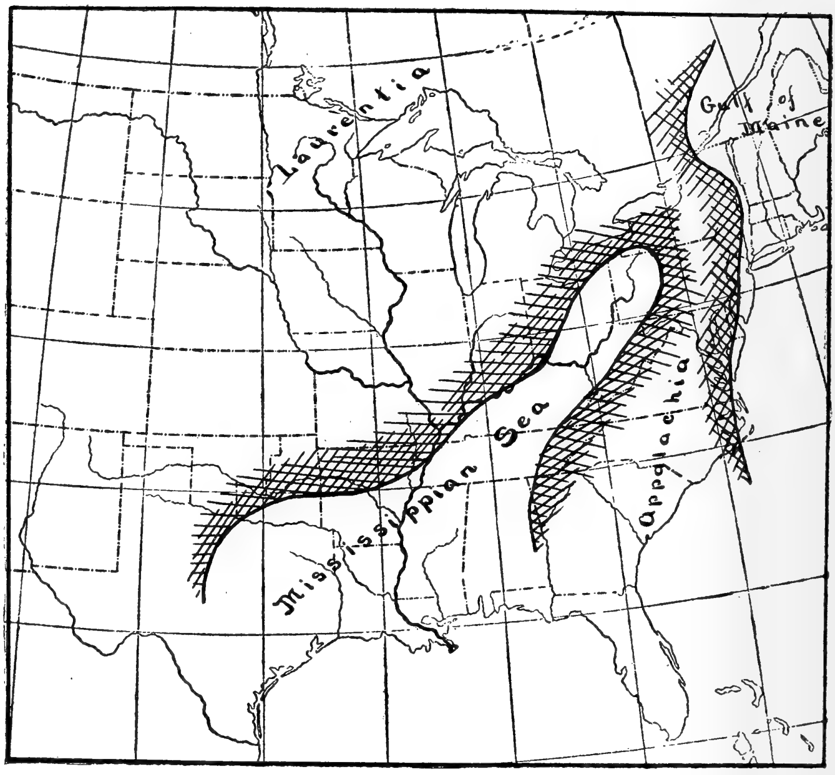


Figure 5.—*Continental Outline at maximum Retreat of the Seas in mid-Saint Peter Time.*

the oscillation, except locally along the margin, there is no evidence of unconformity of angle on a large scale. It appears also that in most localities the sea must have worked over almost the whole sand mantle, while in others the difference above and below the chief zone of disturbance may be the foundation for the occasional suggestion that has been made to divide the formation into an upper and a lower Saint Peter.

At the close of the whole revolution the continental land outlines differed very little from those immediately preceding the Saint Peter epoch.

Paleogeographic Charts

Following out the conclusions involved in the foregoing discussion, the accompanying physiographic charts are presented (see figures 5 and 6). They are an attempt to indicate the land and sea distribution for the Mississippi valley in Saint Peter time. The lines drawn are general-

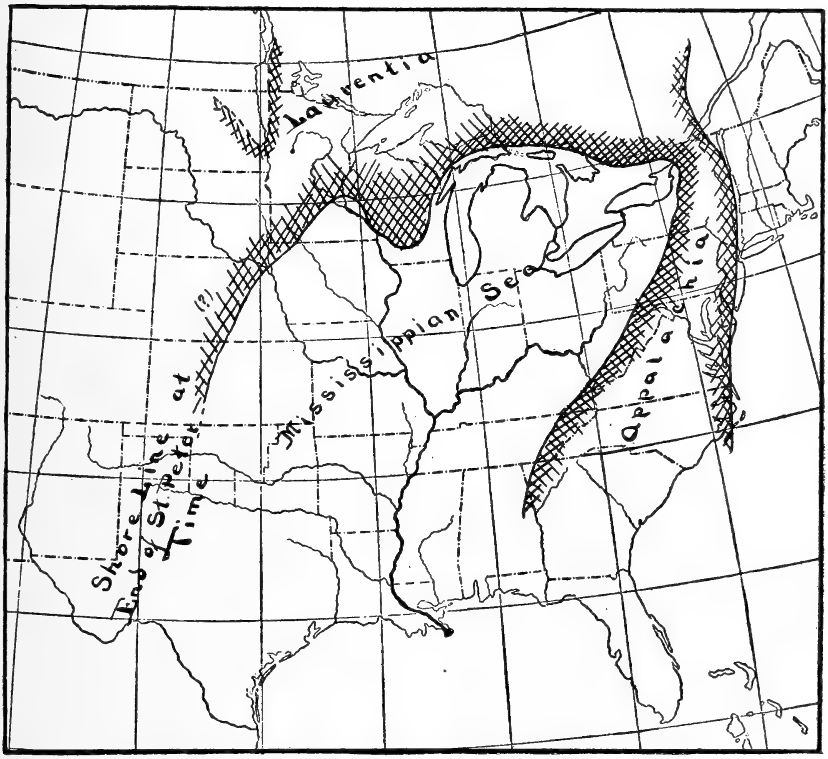


FIGURE 6.—*Continental Outline near close of Saint Peter Time.*

izations and do not aim at local precision. It is intended to be understood that a maximum land area existed in mid-Saint Peter time, followed by a rapid encroachment of the sea to a coastline very like its pre-Saint Peter position.

The maximum retreat is drawn arbitrarily as interpreting the change of character of sediments from offshore to deep-sea types. In the absence of data northward beyond the present limits of the formations involved,

maximum advance margins are held near the existing known outcrops on the thin edges of equivalent beds.

Summary

Such facts as are known about the Saint Peter sandstone have been considered by the writer in support of the following general statements:

The Saint Peter sandstone is a mechanical sediment.

The sands were derived in large part from the upturned edges of preceding beds of sandstone and quartzites bordering the continental areas, and from the Basal Sandstone formation in particular, under conditions that made this an easy and abundant supply. The use of an already assorted material is one step in the production of its unusual characters.

The purity of the formation, the rounded and uniform size of grain, and its wide distribution over such a flat area indicate some agency of extraordinary sorting efficiency and transporting capacity. This is credited to the winds. The folded and faulted character locally of the underlying Shakopee with no effect on the overlying Stones River beds point to dynamic disturbances that occupied the Saint Peter epoch and ceased at its close. Erosional unconformity between the Saint Peter and the Shakopee indicates that the same time was marked by a retreat of the sea. The widespread formation with uniform characters suggests a withdrawal of the sea from a very large area in the upper Mississippi valley.

As a consequence, there was continuous deposition in the south and interrupted sedimentation in the north. The Saint Peter sandstone is stratigraphically a wedge including within itself a wedge-like break. In age the thin southern edge is younger than the lower beds and older than the highest beds, as they appear in the northern areas. The Saint Peter therefore should be found to overlap the Magnesian series seaward, but in turn should be itself overlapped by the limestones and shales of the Stones River group in its succeeding development landward. In certain localities it may be possible to divide the formation into an upper and a lower Saint Peter.

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GLACIAL PHENOMENA OF THE SAN JUAN MOUNTAINS, COLORADO *

BY ERNEST HOWE AND WHITMAN CROSS

(*Presented by title before the Society December 28, 1905*)

CONTENTS

INTRODUCTION

For the last ten years, during which the survey of the San Juan region of Colorado has been in progress, evidence has been accumulating showing that in all probability the mountains have been subject to more than one period of glaciation during Pleistocene time. The fact of more than one stage of glaciation in the Rocky Mountain region was established by Salisbury and Blackwelder † in 1902 through observations made in the

* Published by permission of the Director of the U. S. Geological Survey.

† R. D. Salisbury and Eliot Blackwelder: Glaciation in the Bighorn mountains. Journal of Geology, vol. xi, 1903, pp. 216-223.

Bighorn mountains, Wyoming. More recently, Capps and Leffingwell * have drawn similar conclusions from studies in the Arkansas valley, in Colorado.

Evidence of the last stage of glaciation is obvious in the San Juan mountains, and abundant proofs have been found throughout the region examined that the ice disappeared in relatively recent times.† What may be traces of an earlier stage have been observed at a number of localities, but until lately satisfactory evidence in this connection has been lacking. In the course of the regular field work of the U. S. Geological Survey in the Ouray quadrangle on the northern side of the San Juan mountains, in the summer of 1904, this evidence was found in the Uncompahgre valley, and during the field season of 1905 further data were obtained in adjacent regions.

In presenting the results of these recent observations, the whole subject of glaciation in the San Juan province must necessarily be considered. The character and extent of the last stage of glaciation have been described in several published reports of the Survey, including the Telluride, La Plata, Silverton, Needle Mountains, and Rico folios, and a special report on the geology of the Rico mountains,‡ to which reference should be made for details omitted in this paper, the primary purpose of which is to present the recently observed facts and to discuss their significance in relation to the phenomena observed in other parts of the San Juan mountains.

The last Stage of Glaciation

Character and Extent

The topography of the higher San Juan mountains everywhere shows the influence of glacial erosion, yet the amount of this erosion was slight, merely producing a modification of the earlier topography. Many of the larger valleys are U-shaped. In the pre-Cambrian areas, especially in the upper Animas valley, roches moutonnées are well preserved, and in the higher mountains the majority of the streams rise in typical glacial cirques. The glaciers which accomplished this modification were of the valley type, supplied by the snow fields in the many cirques at their heads, but no evidence has been found of an ice sheet or cap covering the whole

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* S. R. Capps and E. D. Leffingwell: Pleistocene geology of the Sawatch range, near Leadville, Colorado. Journal of Geology, vol. xii, 1904, pp. 697-706.

† R. C. Hills: Extinct glaciers of the San Juan mountains, Colorado. Proc. Colorado Sci. Soc., vol. i, pp. 39-46.

G. H. Stone: The Las Animas glaciers. Journal of Geology, vol. i, 1893, pp. 471-475.

‡ Whitman Cross and A. C. Spencer: Geology of the Rico mountains, Colorado. 21st Ann. Rept. U. S. Geol. Survey, part ii, 1900, pp. 7-165.

region, although in a few favored localities in the very high mountains great névé fields existed, as in the area known as American flat, at the

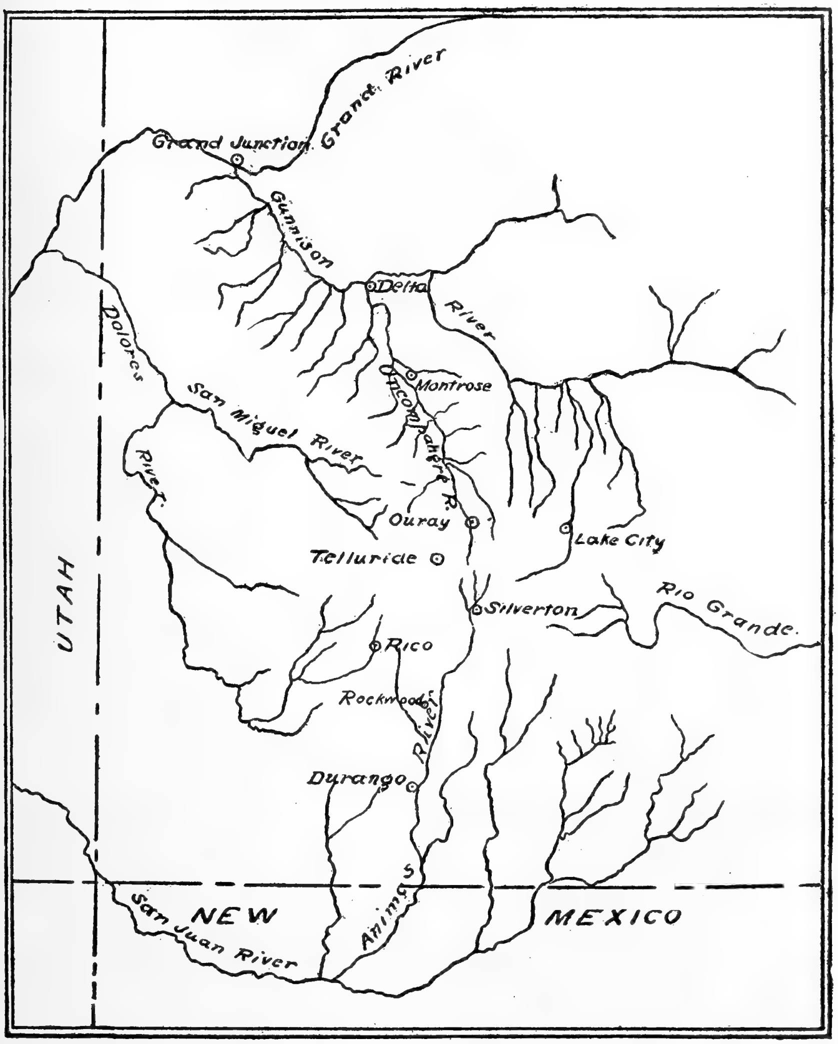


FIGURE 1.—*Drainage Map of the San Juan Region.*

head of Henson creek, and on the Continental divide between the sources of the Rio Grande and tributaries of the Animas and other streams belonging to the drainage of the San Juan river. At many points inter-

mediate between the proximal and distal extremities of the valley glaciers, corrie or cliff glaciers occurred, some of which, together with those in the more sheltered cirques, continued to exist until very recent times. Evidence for this is found in the great freshness of their small moraines and the bareness of the cirque floors. In fact, ice was seen by Cross in 1895 in the large cirque called "The Great Amphitheater" on the Hayden map, which lies west of Mount Sneffels, at the head of a fork of Dallas creek. The ice occurred at the base of the high precipitous southern wall of the basin, a little east of Dallas peak. Although the ice had the appearance of a great snowbank, it was crevassed and of a characteristic green color.

The extent of the glaciers occupying such large valleys as the Animas and Uncompahgre is well shown by their terminal moraines, which lie just within the zone of foothills bordering the higher mountains. No glaciers belonging to this last stage extended as far as the region of low relief generally known as the plateau country. The length of the Animas glacier was nearly 50 miles, of the Uncompahgre not more than 18 or 20. The absence of all terminal moraines in the foothill zone and the relative abundance of drift higher up many of the somewhat smaller valleys would seem to indicate that they contained ice streams that never extended beyond the region of the higher mountains. The Vallecito glacier, which occupied the valley of that name, joining Pine river in the southern foothills, belonged to this class, more characteristic of the south than the north side of the San Juan.

TERMINAL MORAINES OF THE LAST STAGE

Through the borderland of the San Juan an abundance of drift testifies to the extensive glaciation to which the region has been subjected. A great part of this drift is relatively youthful, as shown by the fresh condition of the boulders and the insignificant modification to which the form of the morainal deposits has been subjected.

The great terminal moraine of the Uncompahgre glacier crosses the valley just south of the point where Dallas creek enters and close to the town of Ridgway, about 18 miles from the head of the river (figure 2); it is 400 feet high in places and more than 2 miles long, with an average width of one mile; it has relatively steep upstream faces and gentler slopes down stream. Its surface is uneven and hummocked and contains numerous depressions or kettle-holes. The moraine is cut through about in the middle by the Uncompahgre river, and exposures along the stream show the typical morainal character of the material, which consists of subangular and striated boulders and unstratified gravel and fine sand,

representing all of the rocks known to occur in the upper Uncompahgre and its tributaries.

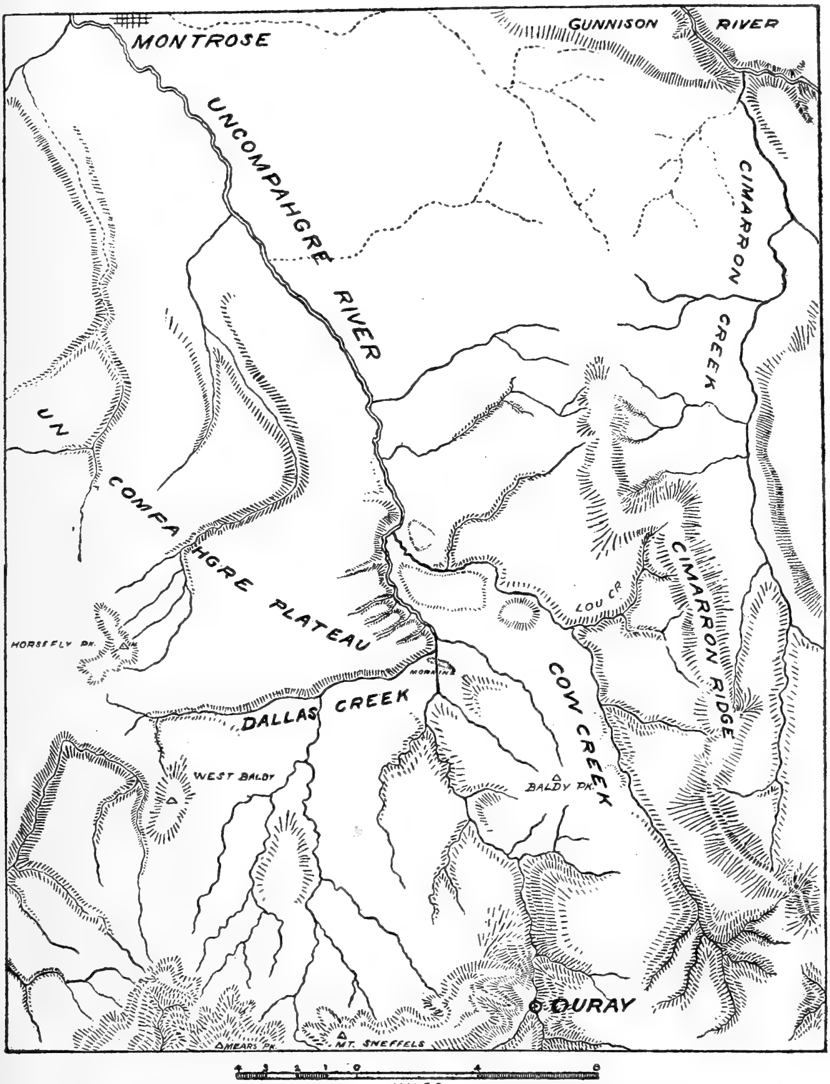


FIGURE 2.—*Sketch Map of the Uncompahgre Valley.*

The only terminal moraines deposited by the long Animas glacier are the two low, parallel gravel ridges crossing the valley at Animas City one

mile above Durango and 12 miles below the mouth of the canyon proper. Plates 30 and 31 represent these moraines in their relation to the gravel terraces to be mentioned in another paragraph. The crests of these moraines are not much more than 100 feet above the river, and are separated by a shallow depression. The Animas has cut a channel through the moraines on the extreme western side of the bottom land.

It seems remarkable that so large a glacier as the Animas, and one more than twice as long as that occupying the Uncompahgre valley, should have left so small a terminal moraine. A reason for this is given in a later paragraph.

The most extensive recent glaciation on the western side of the San Juan was in the various branches of the San Miguel river, within the Telluride quadrangle. While there are in this region many typical glacial cirques and evidence of ice-streams in the deeper valleys is abundant, there are no extensive unmodified morainal deposits corresponding to those of the Animas and Uncompahgre valleys. The principal boulder and gravel masses exhibit marked water action. About Trout lake, on the South or Lake fork of the San Miguel, there is much morainal material, a part of which has been greatly disturbed by landslides. Some discussion of the water-worn and water-sorted gravels of the glacial stage is given in the Telluride folio.

LATERAL MORAINES

The lateral moraines of the glaciers described are, as a rule, not conspicuous features of the topography. They are, perhaps, more prominent in the Animas valley than in the Uncompahgre, and this fact may account in part for the smaller size of the Animas moraine, a greater relative portion of the glacier's load having been deposited on the valley sides than was the case with the Uncompahgre glacier. In this connection may be mentioned the distributary stream from the Animas glacier, which crossed the low divide on the western side at the head of the East fork of Hermosa creek and descended that valley for 6 miles, depositing notable moraines in the neighborhood of Hermosa park. In this way the greater part of the load supplied to the Animas glacier by the tributary from Cascade creek was diverted from Animas valley.

Pronounced lateral moraines occur intermittently on both sides of Animas valley from the terminal moraine to points overlooking the canyon of the Animas above Canyon creek on the east and on the slopes of Engineer mountain on the west. North of these points considerable drift occurs, but it is more in the nature of terminal moraine left by small tributary glaciers of the Animas, while some may represent ground

moraine of the Animas glacier itself. The lateral moraines occur as elongate mounds parallel to the main direction of the valley and rest on the hillsides at elevations from 1,000 to nearly 2,000 feet above the valley near Rockwood, but with gradually lower elevations southward. They seldom rise as much as 50 feet above the surface of the slopes on which they rest. The glacier seems nowhere to have carved benches in the sides of the valley. Two lakes or depressions have been formed, one on each side of the valley, by the damming of gulches by lateral moraines. The rims of these basins are 1,600 or 1,900 feet above the present bed of the river, the highest being on the west side some 2 miles below Rockwood.

Corresponding lateral moraines occur on the sides of Uncompahgre valley, but they are smaller and less perfect in form than those of the Animas. One, however, is noteworthy, especially from the close association of its gravels with those of the terminal moraine. It lies on the slopes of Baldy peak, one of a group of hills between the high mountains and the lowlands, and east of the Uncompahgre river. The long ridge extending northwest from its summit is thickly covered with gravels and huge boulders, the greater part of which was derived from the Uncompahgre glacier; but numerous boulders of massive latite belonging to the later eruptive rocks of the region have come from Cow creek, an eastern tributary of the Uncompahgre. It is believed that the drift covering the ridge, as well as that extending northeast nearly to Cow creek, represents a lateral moraine of the Uncompahgre glacier blending with a similar moraine of Cow creek. The small lateral moraines of the Uncompahgre are more common on the west side, that at the mouth of Coal creek being characteristic of a number that occur between Ouray and the terminal moraine. After running parallel to the valley as a low ridge some 1,000 feet above the river, the moraine turns just before reaching the south side of Coal creek and descends to the level of the present alluvium of the Uncompahgre. North of Coal creek another moraine occurs at the same high level as the first, and after a short distance it also descends. In addition to the more perfectly preserved lateral moraines, drift is found on all the spurs or valley sides that are not too steep to retain such material. In Dexter creek, a tributary of the Uncompahgre from the east, which does not rise in the high mountains and which did not contain a glacier, stratified gravels and coarse sands occur in patches on the valley sides near the present stream, but at elevations well above those at which they could now be deposited by the stream, even at times of flood. The startified character of the gravels is well shown in cuts along the wagon road. They are believed to have been deposited during the last glacial stage by

the waters of the stream held in check by the ice-dam across the mouth of the valley caused by the Uncompahgre glacier.

VALLEY TRAIN

Distinct gravel-covered terraces occur on both sides of Uncompahgre river below the great moraine, and also in Cow creek for 7 miles above its mouth. The surface of these terraces is about 50 feet above that of the present flood-plains of the streams. The gravels are water-worn, stratified, and of only moderate coarseness, individual boulders seldom reaching one foot in diameter, and that only near the moraine; their lithologic character is appropriate to the drainages in which they occur, those of Cow creek being largely of volcanic material, while the ones of the Uncompahgre are of sedimentary and volcanic rocks mingled. The relation of this low Uncompahgre terrace to the great moraine shows clearly that the gravels represent outwash deposits or valley train laid down by waters which issued from the foot of the glacier, and are essentially contemporaneous with the moraine itself. The gravels of the Cow Creek terrace are of the same age and doubtless of similar origin, although their relation to a terminal moraine is not evident. A part of the Cow Creek terrace is shown in the foreground in plate 25, figure 1.

Deposits of similar character and even more extensive occur in Animas valley below the terminal moraines. The terraces covered by them are shown in plate 31 in their relation to the moraines and to still higher terraces, to be discussed later on. It will be noted that the view shows two low terraces beyond the river which blend in some places. It is believed that these levels are due to the outwash of gravel from the glacier, corresponding in the main to different positions of the ice-front, perhaps those of the two moraines.

About 10 miles south of Durango the gravels cover the broad valley of the Animas from the bases of the high mesas east and west of it, shown in plates 28 and 29, and are probably not less than 25 feet thick. The size of the boulders near the terminal moraine is a conspicuous feature of the valley train. Certain of them, representing the pre-Cambrian rocks of the Needle mountains, are from 1 to 3 feet in diameter; but such large blocks are not found at any great distance from the terminal moraine, most of the gravels being well rounded and seldom more than 2 or 3 inches in diameter. This terrace level, like that of the Uncompahgre valley, is about 50 feet above the present level of the river's flood-plain. Similar gravels have been found in the drainage of the San Miguel and Dolores rivers and are abundant along the Mancos, La Plata, Florida, and

FIGURE 1.—LOOKING NORTH OF WEST ALONG COW CREEK

FIGURE 2.—LOOKING NORTHWEST DOWN COW CREEK TOWARD ITS JUNCTION WITH THE UNCOMPAHGRE RIVER

VIEWS ACROSS AND ALONG COW CREEK

Pine River drainages. Special mention has been made of them in the La Plata folio, where they are represented on the geologic map.

TIME OF RECENT GLACIATION

A noteworthy feature of all of the glaciated San Juan region is the very slight erosion that has been accomplished since the disappearance of the ice, shown not only in the channels of the streams, but also in the slight modification in form to which the moraines and drift have been subjected. More erosion, as one might expect, has been acomplished in the soft Cretaceous shales of the foothills and plateau region than in the massive volcanic or pre-Cambrian rocks of the interior. The moraines show little or no effects of weathering, although they have been cut in two by the streams flowing in the main valley. The cuts, however, are sharp, and the exposures on either side are generally fresh and uncovered by vegetation, while in the uneroded portion of the moraine the forms are almost as distinct as they were at the time the moraine was first deposited. This is also true of the lateral moraines, although from their more exposed positions on the hillsides more or less of their material has been carried downward by creep or wash and deposited at lower elevations. The freshness of the materials constituting the moraines is very striking; the boulders are superficially almost entirely unoxidized and many show distinct striations. This holds true, not only of the harder pre-Cambrian rocks which constitute a large part of the Animas moraine, but also of the Paleozoic and later rocks which are quite abundant, boulders or pebbles of compact limestone being not uncommon.

Many of the higher cirques are practically in the condition in which they were left by the ice, their floors being bare and no erosion having been accomplished by the streams which now occupy them. The greatest erosion has naturally taken place at points intermediate between the cirques and the flood-plains of the main streams; thus, in Needle creek, a tributary of Animas river, the stream has intrenched itself to a depth of 2 or 3 feet in the old rock floor, but at many places actually flows over glacially polished surfaces. Even in regions of softer rocks the post-glacial erosion has been very slight.

As already mentioned, ice has been observed in one of the high cirques of this portion of the Rocky mountains, and in other areas in Colorado actual glaciers, although of small size, are known to occur, as, for example, the now well known Arapahoe glacier in the front range, 20 miles west of Boulder. All of this evidence is of interest and importance in showing the relatively recent time in which actual glacial conditions existed in the San Juan mountains and probably throughout the Rocky moun-

tains in general, and that this, the last stage of glaciation, undoubtedly extended from Pleistocene into Recent times. Emphasis is laid on this point in order to bring out by contrast the greater age of the other deposits which are to be described.

Occurrence of Drift older than the last Stage of Glaciation

GENERAL CHARACTER AND DISTRIBUTION OF THE DRIFT MATERIAL

As was mentioned in the introduction, deposits of supposed drift and gravels have been observed at many localities on the outskirts of the San Juan mountains which are evidently older than the deposits of the last stage of glaciation. Much of this detritus consists of water-worn and stratified gravel clearly deposited by streams and at elevations considerably higher than those at which the streams now flow. Traces of these gravels have been found many miles from the mountains and far beyond the observed limits of the deposits of the last glacial stage. Some of the detritus may be morainal, but if so the form of the deposits has been so modified that often they may be overlooked, while the materials constituting them appear to be less fresh than those of the last moraines.

The first definite information bearing on the origin of this detritus and its evident greater age than that of the last stage of glaciation was found in Uncompahgre valley and the territory immediately adjoining it in the summer of 1904. The following account, supplemented by observations made by Cross in 1905, is given in some detail, since the facts observed in this locality have a direct bearing upon the occurrence of drift elsewhere, in regard to the origin of which information has hitherto been lacking.

REGION IN WHICH THE OLD DRIFT OCCURS

After leaving the high mountains, the Uncompahgre river, as shown by the sketch maps, figures 1 and 2, follows a course slightly west of north to its junction with the Gunnison river. Once beyond the limits of the volcanic rocks, the stream enters an open valley flanked on the east by Cimarron ridge, or "Tongue mesa" of the Hayden map, and on the west by the Uncompahgre plateau. The main stream, together with its upper branches, drains one of the highest parts of the San Juan mountains, representing an area of about 100 square miles, composed largely of Tertiary volcanic rocks—tuffs, agglomerates, flows, and intrusive porphyries—through which the river has cut and exposed a great section of Algonkian and later sediments which underlie the volcanics. From the sources of the different streams to the broad open valley of the Uncompahgre the topography is extremely varied. The line between the plateau

Figure 1.—Looking Northwest across Uncompahgre Plateau from Horsefly Peak

Figure 2.—Ridge extending Northward from Horsefly Peak

UNCOMPAHGRE PLATEAU FROM HORSEFLY PEAK, AND RIDGE EXTENDING NORTHWARD FROM LATTER

country of moderate relief and the high rugged mountains is a sharp one, several peaks of the border zone, having elevations in the neighborhood of 14,000 feet, rising abruptly from 7,000 feet often without intervening foothills. Most of the streams head in glacial cirques far above timber line, drop into deep canyons which open out into U-shaped valleys as they leave the higher mountains, and then, quite as suddenly, enter broad valleys eroded in soft Cretaceous shales.

The topography of the region in which the deposits of old drift occur is characterized by the presence of broad valleys or drainage basins which have been dissected during more than one period of erosion. Before dissection the region was one of very moderate relief, with low divides between the streams, and it is upon these old surfaces, or those developed during the intermediate periods of erosion, that the gravels and drift occur which are believed to be older than the last stage of glaciation. Near the Uncompahgre river the relation of the old surface to the flood-plains of the present streams and to certain intermediate levels is well shown. These features are brought out in plate 25, which, with the aid of the accompanying descriptions, should give a clear idea of the topography.

THE DEPOSITS OF EARLIER DRIFT

West of the Uncompahgre river and north of Dallas creek is an elevated region whose almost plane surface is inclined slightly to the northeast; it is the extreme southeastern extension of the Uncompahgre plateau, which, as shown by the Hayden map, extends northwest for nearly 70 miles. About 10 miles due west from the junction of Dallas creek with the Uncompahgre river (figure 2), Horsefly peak, a small hill, whose elevation is about 10,000 feet, rises 600 feet from the surface of this plateau. The peak itself is the culminating point of a line of low hills which extends in a northerly direction from the divide at the head of Dallas creek to a little beyond Horsefly, where the line turns somewhat to the west and the hills rapidly decrease in elevation; they form the crest of the divide between the Uncompahgre and San Miguel rivers. These hills are covered so thickly by pebbles, boulders, and blocks of volcanic material, often 10 or 15 feet in diameter, that in many places the hills have the appearance of being entirely composed of the detritus (see plate 26). The material was derived almost entirely from known late volcanic flows and breccias of the mountains and appears to have been once partly rounded or subangular, but has been much modified in form through weathering. In addition to the late volcanic rocks, there is a little granite and Algonkian quartzite, probably derived from an early Tertiary conglomerate, which in age immediately precedes the volcanic rocks and which is known to occur in the

mountains to the south and east. The mass of the hill beneath the gravel is composed of Cretaceous shales resting on the Dakota sandstone, which forms the capping formation of the plateau, and it is probable that many of the moraine-like hillocks and depressions resembling kettle-holes may be due to the uneven erosion of the shales, but in a few places it is possible that true morainic forms exist, although much modified by erosion and weathering.

Similar deposits occur on West Baldy, 5½ miles south of Horsefly peak, a noteworthy feature of their occurrence being the abundance of late volcanic rocks and intrusives and the small amount of the early breccias. These intrusives are found in place about 8 miles to the south, and, together with the early andesitic breccias, make up a large part of the mass of Mears peak west of mount Sneffels. The late volcanic rocks, belonging to the Potosi volcanic series of recent reports, now occur only as thin remnants of flows capping the highest peaks and constitute but a small part of the range of mountains forming the northwest buttress of the San Juan. The abundance of such material in the West Baldy and Horsefly detritus has much significance in considering the age and origin of these deposits, subjects which are discussed in a later paragraph.

Ten miles north of Horsefly peak and at an elevation of about 8,000 feet, a small kame-like hill rises, probably not more than 100 feet, above the gently inclined surface of the Uncompahgre plateau and about midway between the crest of the plateau and the Uncompahgre river. This hill is made up of rounded boulders and gravel, mainly of dark volcanic rock, some of the larger boulders being several feet in diameter. The hill is isolated and such igneous material is not commonly scattered over the surrounding country. Other similar knolls occur between this point and Montrose. Southeast of Montrose, along a road leading toward the end of the Cimarron ridge, there are small remnants of boulder and gravel deposits consisting mainly of volcanic debris. These gravels form low knolls, rising above the graded surface of the Cretaceous shales, and are conspicuous, since they are of different composition from the hills of shale which may also be noted here and there. The largest boulders of volcanic material occurring in the knolls are probably not more than 2 feet in diameter.

The slopes extending from Cimarron ridge to Cow creek, whose course is nearly parallel to the trend of the ridge, as shown in the sketch map, figure 2, are more or less thickly covered with gravels and boulders. The debris lies in disordered heaps, modified somewhat by erosion, but in places retaining a form which suggests ice deposition. The material consists of pebbles and boulders derived from the agglomerates of the ridge

and in addition large crumbling blocks of the agglomerate itself. Near the ridge these deposits are covered by the debris of recent landslides from the cliffs of the ridge. Except where obscured by landslide, the slopes westward from Cimarron ridge have even grades of low slope, such as are characteristic of a mature topography, but they have been materially modified by a renewed activity of the streams draining them, and the gravels are preserved in their original positions only on the divides and ridges between the intrenched streams.

ORIGIN OF THE DRIFT

The brief examination made failed to disclose any striated pebbles in the material occurring on Horsefly and West Baldy, but there are other sufficiently good reasons for believing that the deposits are of glacial origin.

The study of the material represented in the two occurrences shows that it was derived from the high mountains to the south and from which Horsefly peak is now separated by the broad and deep depression of the Dallas drainage basin. A very large part of the material consists of late volcanic rocks, now preserved only as remnants capping the highest summits, which are at some distance to the east. There are also numerous boulders of intrusive porphyry which can have come only from Mears peak, while there is a notable absence of the gabbro occurring on Mount Sneffels and only a slight representation of the early braccias which constitute a large part of the adjacent mountains. There can be no doubt that the material covering West Baldy and Horsefly peak as well as that composing the kame-like hill to the north was derived from the mountains to the south or southeast; but since its transportation from its source the mountains have undergone extensive degradation, and the younger rocks represented in the West Baldy and Horsefly gravels have been largely removed and older formations exposed.

Evidence has been found at the foot of the mountains that at various points between the Uncompahgre river and the northwest end of the range landslides occurred on an enormous scale before the dissection of the old lowland, previously mentioned, had begun. The deposits of the old landslide material closely resemble more recent deposits of similar origin, but the rough surface and peculiar topography characteristic of young slides has been much softened and modified by age. Probably the most striking feature of this old landslide material and the best indication of its age is the intimate relation it bears to the old topography and the absolute independence of its position to the present-day topography. The material occurs, beneath the comparatively smooth surface, in characteristically

chaotic masses of hugh blocks and finer and more completely shattered material on the crests of ridges between the modern streams or on isolated mesas. Just west of the Uncompahgre river are noteworthy occurrences, some of the material extending northward nearly 4 miles from the present base of the high mountains. Another striking instance was found at the extreme northwest end of the range, where landslide debris covers the top of a hill whose nearly plane, though inclined, surface if extended would meet the near-by spur of the mountains at a point not far below its present summit. These relations are shown in plate 27. The landslide material consists of late volcanic rocks entirely. The mountains immediately to the east are made up wholly of early andesitic breccia and intrusive andesite, although still farther east remnants of the late volcanics are preserved on the highest summits. These conditions seem to indicate that at the time the landslides occurred a much bolder topography existed in the higher mountains than prevails at the same points today, and that the younger and higher formations which crowned the summits have been more or less completely removed, possibly in part through the agency of the very landslides under discussion.

The relatively great distance from its source at which some of this ancient landslide material has been found suggests that the detritus on West Baldy and Horsefly may have had a similar origin; but the difference in physical character between this detritus and that of the landslides, the greater variety of the materials represented in the West Baldy and Horsefly occurrences, and finally the much greater distance from its source at which, in the case of Horsefly at least, the material is found, would seem to be sufficient reason for rejecting such an hypothesis.

The possibility of water or torrential transportation of the Horsefly material also seems unlikely. The detritus lies near, if not actually on, the divide which separates the drainage areas of the Uncompahgre and San Miguel rivers, and the remnants of the old topography show that at the time the detritus was deposited the streams and their tributaries flowed in very wide open valleys in essentially the positions that they occupy today. If the Horsefly and West Baldy material is to be regarded as contemporaneous with the kame-like deposits observed to the northeast in the direction of Montrose, it is difficult to conceive how blocks 10 or more feet in diameter could be carried far out on the western divide at least 10 miles from the mountain front.

It is known that the bedded volcanic rocks of the region once extended some distance out over what is now the plateau country, and that they have since been removed by erosion, but the detritus covering West Baldy and Horsefly can hardly be regarded as representing what Shaler has

LOOKING SOUTHWARD FROM A POINT FOUR MILES SOUTH OF WEST BALDY

aptly termed "residual ablation deposits," or detritus slowly let down by the removal of softer or more soluble material, since it is composed, not only of material derived from the bedded volcanics, but also of intrusive porphyries, evidence of which should be found today in the immediate vicinity in the form of dikes or stocks, none of which, however, has been discovered. Moreover, such an explanation would apply only to the detritus on or near the divides and could not account for the material occurring at lower levels near Montrose. Taking all these facts into consideration, there seems to be sufficient ground for assuming that the detritus can only be of glacial origin and is to be regarded as true drift. From its position, that of West Baldy and Horsefly is most naturally to be considered as lateral moraine, while the deposits occurring at lower elevations near Montrose may represent remnants of the terminal moraine or ground moraine. Detailed information in regard to those last occurrences is lacking, the mere fact of their existence and the general character of their materials being known.

The origin of the detritus between Cow creek and Cimarron ridge is not altogether clear. The nature of the material indicates that it was derived only from the early tuffs and agglomerates which constitute the ridge, and the abundance of recent landslides from the ridge presents the possibility that this evidently older material may have had a similar origin. There is one strong objection to accepting this as an explanation. The material lying between the streams, and apparently only very slightly affected by erosion since the time of its deposition, is usually less abundant near the cliffs from which it was derived than it is farther away. Its most characteristic occurrence also is in the form of mounds or heaps of large and small blocks often separated from one another by several hundred yards of bare ground covered only by the soil which results from the weathering of the underlying Cretaceous shales. As has been said, the composition of the material shows that it was derived from Cimarron ridge, but its disposition could not be accounted for by the simple agency of landslides. For the same reason the material could hardly have been deposited by streams, and even torrents could not have transported blocks from 10 to 30 feet in diameter three or four miles from their source. Water-laid gravels do occur, as is shown later, just beyond the limits of this unstratified detritus; they belong to the highest series and rest upon the old land surface that has been frequently referred to. It seems evident that these deposits can not be regarded as lateral moraine of an early Cow Creek glacier corresponding in time to the Horsefly deposits because none of the various types of rock known to occur along the upper portions of Cow creek are found, the deposits con-

sisting of the early breccia of Cimarron ridge unmixed with other rocks. At the time these observations were made, before the Horsefly drift had been discovered, it was thought that the mounds and heaps of debris might represent material which fell from the cliffs of the ridge on snow fields or névé, and that it was thus transported relatively short distances and deposited by the névé ice without having the form of a moraine built by a well defined glacier. There is today no trace of a divide between the old valleys of the Uncompahgre and Cow creek, but from the elevation of the Horsefly drift, 10,000 feet, it must be assumed that the ice stood at a nearly corresponding level on the east side of Cow creek, whether or not the glaciers united nearer their sources than the junction of the present streams. If this assumption be correct, the supposed drift between Cow creek and Cimarron ridge can have been deposited only after the glaciers of the early stage had begun to shrink, since the drift occurs quite a little below the 10,000-foot level, and the stratified gravels below them, already referred to, appear to have been contemporaneously deposited—a relation which could not exist had the main valley been filled with ice at the time the supposed drift was laid down. Although it seems not impossible to attribute these deposits to such an origin as has been suggested, yet it must be admitted that satisfactory proof is lacking. On the other hand, no other explanation to account for the existing conditions seems acceptable.

EARLY TERRACE GRAVELS OF COW CREEK

Gravel-covered terraces occur at two well marked levels below the supposed old drift and above the younger valley train. The upper terrace, shown in plate 25, figure 2, on the extreme right, is merely an extension of the old graded surface on which the drift rests and is covered by stratified and water-worn gravels separated by rather an indefinite line from the drift. The terrace form and gravel cover are preserved only as remnants between the streams tributary to Cow creek and in a few isolated hilltops and mesas, one of which lies west of Cow creek 4 miles from its mouth and is shown in plate 25, figure 2, on the left. The gravels of the Cow Creek drainage consist entirely of material derived from the volcanic rocks and vary in size from a few inches to a foot in diameter. The deposits are of variable thickness and are usually thin near the old supposed morainal material. The maximum observed thickness is 50 feet near the edges of the terraces overlooking Cow creek and on the mesa a short distance from the mouth of Cow creek, which are the only points where the gravels are well exposed, as they are elsewhere covered by 2 or 3 feet of fine, reddish soil, possibly of eolian origin. The

relation of these gravels to the old drift, as well as their stratification, suggests that they may represent a combination of outwash deposits from the ice which deposited the early drift below Cimarron ridge as moraine and from the retreating Cow Creek glacier.

A second gravel-covered terrace occurs below the first one in Cow creek. On the southwest side of the creek, as shown on the mesa about 4 miles from the mouth (plate 25, figures 1 and 2), the vertical distance between the two terraces is about 100 feet, while on the northeast side 300 feet intervenes between the two. Intermediate terraces occur at a number of levels, but they are poorly preserved and merge one into another, so that correlations are impossible. Remnants of this lower level are preserved as benches or isolated mesas on both sides of Cow creek and the Uncompahgre river and are striking topographic features.

The highest gravel-covered terrace has not been identified west of the Uncompahgre river in the vicinity of Dallas creek, but about 6 miles to the north, just beyond some low hills due to an intrusive porphyry, it is well preserved. Close to the river at this point the line between the highest and intermediate terraces is sharp, but in the direction of Horsefly peak it soon becomes indistinct, and the two surfaces appear to blend into one another. The terraces bordering directly on the Cow Creek drainage are covered by gravels composed almost entirely of late volcanic material, those of the lower levels being well rounded and water-worn, and, like the ones of the upper level, covered with fine, red soil. The terrace gravels of the Uncompahgre drainage belonging to the lower level accord closely with those of Cow creek in elevation, but the materials are different, consisting of massive late volcanic rocks, porphyries possibly derived from the Eocene conglomerate, and examples of nearly all the sedimentary rocks of the upper Uncompahgre, including Algonkian quartzite.

INTERGLACIAL EROSION

It is clear that a long period of erosion occurred between the times of deposition of the older drift and the fresher and younger material. During this period the mesas west of Cow creek were developed, the surface of the one about 4 miles above the mouth of the creek being a remnant of the slopes still preserved between Cow creek and Cimarron ridge, while the other somewhat lower mesas correspond to the level of the lower terraces (plate 25, figures 1 and 2). Evidence has been found in the higher mountain region to the south that the canyon of Cow creek was probably developed at this time, as the old graded slopes west of Cimarron ridge may be traced more or less continuously all the way to the head of Cow creek; it is below these that the present canyon lies. Taking this

into consideration, it seems more than likely that the gravels of the lower terrace represent the deposits incident to this interglacial erosion. They might, of course, be regarded as valley train deposited during an intermediate period of glaciation, whose drift it has been impossible to differentiate from that of the earlier and later periods.

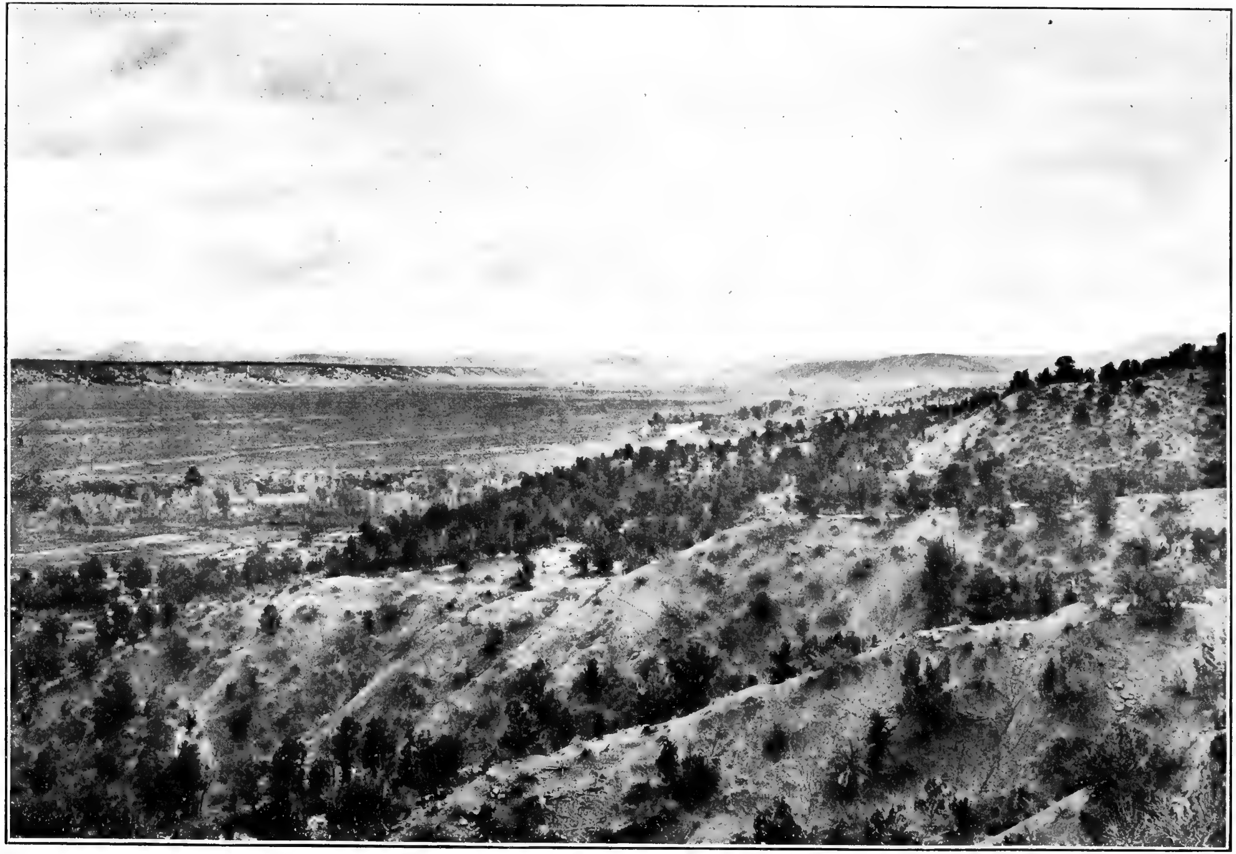
GRAVEL-COVERED TERRACES OF THE LOWER ANIMAS AND SAN JUAN RIVERS

The existence of widespread deposits of terrace gravels in the region south of the San Juan mountains has long been known; they are mentioned in the reports of nearly all the early explorers, but no explanation of their presence has been offered. Recently Cross has made further observations on them, but as the greater part of the Survey field work has been confined to the mountains, it has been impossible to make as complete a study as could be desired of their character and distribution. All the tributaries of the San Juan river heading in the mountains exhibit in their valleys several gravel-covered terrace levels, which extend at least as far down the San Juan as the mouth of the Mancos and probably much farther.

The terraces of the Animas valley are best known and may be taken as typical of all those in the San Juan basin. The upper limit of the lower and intermediate gravel terraces is shown in plate 31. These two gravel plains expand greatly just below Durango, and their development at 7 or 8 miles below the town is shown in plates 28 and 29. The lowest is that of the valley train of the last glacial stage already mentioned; its surface is roughly 50 feet above the present flood-plain of the Animas. The next higher terrace level is represented by the Florida mesa on the east side of the Animas river, while on the west there is a corresponding slope which rises to the low divide which exists betwee nthe Animas and La Plata drainages. Between these higher and lower terraces there are several intermediate levels, some of which are especially well preserved east of the Animas river between Durango and the moraines (plate 31). Like the ones on the north side of the San Juan mountains, they are gravel-covered, and resting on the gravels is a variably thick layer of fine eolian soil. In plate 29 traces of a higher level or levels are seen in the flat-topped hills or mesas in the far distance.

These three main gravel horizons may be traced down the Animas to the broad San Juan valley, and down the latter to the point, some 50 miles southwest of Durango, where the upturned strata of the Mesaverde coal-bearing formation cross the river at the Great Hogback, or "Creston," as it is called on the Hayden map.

LOOKING NORTH UP THE ANIMAS VALLEY



LOOKING SOUTH DOWN THE ANIMAS VALLEY

In the vicinity of Fruitland, a few miles east of the Great Hogback, the two lower gravel horizons are well exhibited. The intermediate one, at least 150 or 200 feet above the lowest, may be seen capping the ledge of white Laramie (?) sandstone, known as the "Pictured rocks." Here the gravels were found by Cross to consist of large and small boulders and pebbles of many volcanic rocks, of granite and schist, and notably of the extremely hard Algonkian quartzites of the Needle mountains. Boulders as much as 3 feet in diameter were noted and many of 1 and 2 feet diameter. Isolated gravel-capped hills, often of level top, and rising above this gravel plain of the Pictured rocks, occur on both sides of the San Juan.

The beautiful gravel terraces on the south side of the San Juan, opposite the Great Hogback, form the subject of a sketch by Holmes in the Hayden Report for 1875 (plate xxxix), and a photograph taken by Cross of the same view has been used by Gilbert and Brigham in their "Introduction to Physical Geography" (figure 36), but erroneously entitled as representing "Terraces of the Uncompahgre valley, Colorado." Inasmuch as the terraces of the San Juan extend with visible continuity far below the Great Hogback, it is almost certain that they are gravel-covered for many miles beyond the limit of present observation, near the Great Hogback. The coarseness of the gravels at this locality renders such an assumption natural.

Northward from the San Juan river, terraces and plains, seemingly extensions of those which are gravel-covered, reach far up the Mancos valley and across to the slopes of the El Late mountains. It appears probable that, whether gravel-coated or not, these topographic features are contemporaneous in origin with those under discussion here.

On the western side of the San Juan mountains, in the valleys of the Dolores and San Miguel rivers, gravel benches are known several hundred feet above the present stream beds, but only near the mountains, as far as our observations go. It is probable, however, that these elevated gravels will in time be correlated with some of the more extensive deposits of the northern and southern slopes of the San Juan mountains.

During a reconnaissance made in 1905, Cross noted the absence of gravel deposits over the Dolores plateau between Mancos and the Abajo mountains, but about this group, as also around the La Sal mountains, there are evidences of ancient local gravel terraces or plains extending for some miles farther from these local uplifts than do the moraines of the recent glaciers. The latter ice-streams in both of these mountain groups of the plateau country scarcely extended beyond the sharply defined zone between mountain and plain.

Although it has been impossible to trace these three principal levels around the western side of the San Juan mountains, there can be little doubt that the ones on the south are to be correlated with the similar ones of the Uncompahgre river. The relation of the lowest terrace to the last stage of glaciation and directly to the moraine north of Durango is clearly shown, and also the relation of this terrace to the one next above, known locally as the Florida mesa, is essentially the same as that existing between the lowest and intermediate terraces of the Uncompahgre drainage. That the remnants of a still higher terrace shown in the isolated hills and mesas along the lower Animas river may correspond to the highest terrace of the Uncompahgre seems not unlikely, but this level has not been recognized in the immediate vicinity of the mountains, and no early drift corresponding to that of the Uncompahgre region has been thus far observed on the southern side of the San Juan either in the Animas drainage or that of the other south-flowing streams, such as the Florida and La Plata, that have been examined. On the whole, it seems most probable that the origin of the terraces and of the gravels which cover them on the south side of the San Juan mountains was analogous to or actually the same as that of the terraces on the north.

Comparison with similar Deposits elsewhere in the Rocky Mountain Province

At least two series of glacial formations have been recognized by Salisbury and Blackwelder * in the Bighorn mountains of Wyoming. The second stage was apparently altogether similar to the later stage in the San Juan mountains, but probably somewhat more drift was deposited, or at least is now preserved. The same freshness of the materials is notable in each region, and in each case but a small amount of erosion has taken place since the disappearance of the ice. It is interesting to note that five small glaciers still exist in the Bighorn mountains. The occurrence of older drift in that region is more noteworthy than in the San Juan region, as it is more abundant, and the morainal characteristics of glacial deposits often well shown. The deposit in Wyoming referred to is very discontinuous, and the greater part, as in the San Juan region, is restricted to hilltops. Evidence was also found, although conclusive proof was lacking, that in Wyoming a still earlier period of glaciation occurred. Gravels and large boulders 15 to 25 feet in diameter were observed on isolated spots 8 or 10 miles away from their source, and their decomposed condition was most noteworthy. On the whole, from the authors' descrip-

* Op. cit.

TERMINAL MORAINES OF THE ANIMAS

tion, these last deposits seem to resemble the early ones of the San Juan more than do the intermediate ones. It is possible that the intermediate terraces in the San Juan, which have been attributed to erosion alone, may correspond to the earlier glaciation in the Bighorns, but that in the San Juan region actual glaciation was very feeble or altogether lacking. At the time that observations were being made in the San Juan region Capps and Leffingwell * were examining the Pleistocene deposits of the Arkansas valley in Colorado. Two definite epochs of glaciation are noted by them, and, as in the Bighorns, the possibility of a still earlier one is recognized, although here also satisfactory proof of this is lacking. The deposits of the last stage are of essentially the same character as those of the San Juan, with the exception that lateral moraines are perhaps more prominent in the valleys of the Sawatch range tributary to the Arkansas. The deposits of the older drift are characteristically weathered and of patchy occurrence and are found higher than the younger drift and beyond the limits of the last ice. In addition to the strictly morainal deposits, two distinct gravel-covered terraces were observed. Both of these terraces are in close relation to the moraines of the earlier and later epochs, and in this correspond to the highest and lowest terraces of the Uncompahgre valley. The authors have noted no intermediate terrace levels between the upper and lower ones, but the older drift, whose character is still open to doubt, occurs at a yet higher elevation, and here again it may be found to correspond in age to the deposits on Horsefly peak of the San Juan region, and the intermediate levels of the San Juan in turn correspond to the older drift levels of the Arkansas valley.

Whether these suggested correlations prove to be true or not is more or less immaterial in the present connection, the important point being that at least two definite and distinct epochs of glaciation have been recognized at a number of widely separated points in the Rocky Mountain province, and that the interval which occurred between them was one of long duration and in which extensive erosion took place.

A more systematic examination of the Pleistocene deposits of the San Juan region than has been possible up to the present time would undoubtedly throw light on many points that are at present obscure in regard to the relative age of the drift and its relation to the various terrace levels. Direct evidence would also doubtless be obtained bearing on the nature and cause of the intervals of active erosion which occurred between the different advances of the ice. At present it is impossible to say to what extent climatic conditions played a part during these periods of erosion. That actual uplift occurred seems certain, but the nature of the uplift is

* Op. cit.

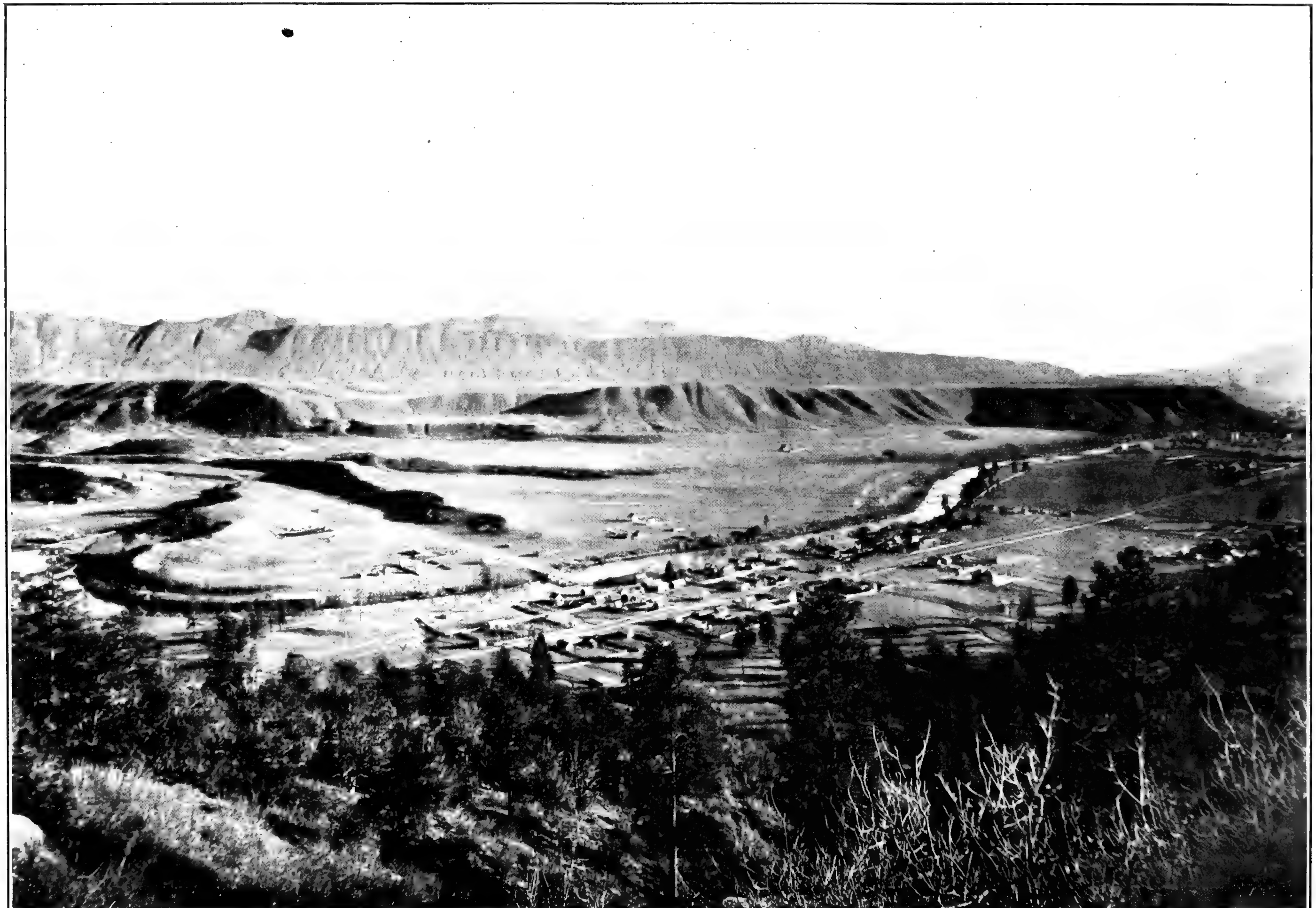
as yet unknown and may prove to have been of a differential character and marked by local warpings or movements in one locality which did not occur at another. Any discussion of such matters based upon our present knowledge is beyond the scope of the present paper.

Summary.

The events of the later stage of glaciation in the San Juan region are recorded in a slight but characteristic modification of the topography, and in an abundance of drift in the form of moraines and outwash gravels which is oxidized but little and on which subsequent erosion has had slight effect. Postglacial erosion has been insignificant in the higher mountains, and it is believed that glacial conditions continued to exist until comparatively recent times.

The older detritus occurs farther from the mountains than the more recent drift and rests on the remnants of an old topography which was deeply dissected before the time of the last stage of glaciation. The form of the deposits suggests that they have undergone much modification by erosion, and the materials composing them have been more or less decomposed by atmospheric agents. There is a marked contrast between the appearance of this drift and that deposited by the last glacial ice. The large size of individual boulders, the number of different rock types represented in the material, and their distance from the source from which they were derived suggest transportation and deposition by glaciers as the most plausible explanation of the origin of these deposits.

Stratified deposits of water-worn gravels closely related to the older drift in age and position extend far out from the mountains and are regarded as outwash deposits incident to the earlier glaciation. Between these highest gravels and the valley train of the last stage of glaciation several intermediate gravel-covered terraces occur that are believed to have been developed during the period of interglacial erosion which accomplished the dissection of the old surface on which the early drift was deposited.



LOOKING SOUTHEAST ACROSS THE ANIMAS VALLEY

Description of Plates

Plate 25.—*Views across and along Cow Creek*

Figure 1.—Looking north of west across Cow creek.

The view is from a point just south of the mouth of Lou creek. Dallas creek is in the far distance to the left, the eastern extension of the Uncompahgre plateau in the distance to the right, the highest point on the skyline being Horsefly peak. The low hills in the middle distance lie between Cow creek and the Uncompahgre river. The mesa to the right is covered with gravels of the intermediate stage; the terrace in which Lou creek has entrenched itself in the foreground corresponds to the level of the outwash deposits of the last stage of glaciation. The photograph is from a hill covered with coarse gravel corresponding to that of the high plain seen on the right of figure 2.

Figure 2.—Looking northwest down Cow creek toward its junction with the Uncompahgre river.

View is from a point just south of Lou creek. The lowest terrace bordering Cow creek and corresponding to that of the valley train of the last stage of glaciation is shown in the middle distance. The mesa to the left belongs to the old valley surface upon which the early drift and gravels were deposited, and corresponds to the slope on the right which descends toward Cow creek from Cimarron ridge; both are gravel-covered. Part of the Uncompahgre plateau is shown in the far distance.

Plate 26.—*Uncompahgre Plateau from Horsefly Peak and Ridge extending Northward from Latter*

Figure 1.—Looking northwest across Uncompahgre plateau from Horsefly peak.

The early drift covering the peak and the neighboring hills is shown in the foreground.

Figure 2.—Ridge extending northward from Horsefly peak.

The ridge is covered with early drift.

Plate 27.—*Looking Southward from a Point 4 miles South of West Baldy*

The mountains to the left are the most northwesterly of the San Juan group. The inclined mesa to the right has exposed upon its surface at its highest point traces of ancient landslide debris that is believed to have been derived from the adjoining mountains at some time before the present topography was developed, when the surface of the mesa formed part of a continuous slope from the mountains, which were higher than at present.

PLATE 28.—*Looking North up the Animas Valley*

The view is from a point about 10 miles south of Durango. The broad terrace covered by the gravels of the last valley train is shown to the right; above it is the western part of the Florida mesa, a corresponding level being shown to the left. The hills in the distance consist of upturned cretaceous rocks directly south of Durango.

PLATE 29.—*Looking South down the Animas River*

The view is from a point about 8 miles below Durango. The lowest terrace and Florida mesa are shown on the left, while in the distance still higher gravel-covered terraces are shown.

PLATE 30.—*Terminal Moraines of the Animas*

The view is from the west and shows the two moraines near the middle of the picture beyond the east bank of the river. The higher gravels of the Florida mesa level occur on the prominent bench to the right between the moraines and the high ridge forming the skyline; the southward extension of this terrace is shown in plate 31. The old town of Animas City is in the foreground.

PLATE 31.—*Looking Southeast across the Animas Valley*

The view is from a hill above Animas City. The two moraines are shown on the left, with the terraces covered with outwash gravels beyond them. The level of the prominent terrace above the lower ones is the same as that of Florida mesa, shown some miles below in plates 28 and 29. The site of Durango appears at the extreme right.

TOPOGRAPHIC SKETCH MAP OF PORTION OF WESTERN ARIZONA

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GEOLOGY OF THE LOWER COLORADO RIVER*

BY WILLIS T. LEE

(Presented in abstract before the Society December 29, 1905)

CONTENTS

INTRODUCTION

The purpose of this paper is to describe in a general way the occurrence of certain detrital accumulations in the southwestern part of the United States, and to suggest a line of investigation which apparently makes clear the recent geologic history of that region. The statements contained in the paper are supported by evidence which must be here omitted for want of space. On the other hand, the fact is recognized that in a region so extensive and so little known as that in which the detrital accumulations occur, much more work must be done before final conclusions can be reached. The observations on which this paper is based were made mainly during rapid reconnaissance trips in western Arizona, although detailed work was done in a number of places in the Southwest,

* Published by permission of the Director of the United States Geological Survey.

notably in Salt River valley in central Arizona, Owens valley in eastern California, and in the Rio Grande valley in New Mexico.

Geographic Distribution of Detritus

Over a large part of the Southwest, extending from New Mexico to the Pacific ocean, detrital material fills the low places generally and transforms into broad detrital plains districts which might otherwise have very uneven surfaces. In Arizona, where the writer has observed the deposits most widely, the detritus occupies the lowlands to the south and west of the Colorado plateau.

There are three general topographic provinces in Arizona—the high Colorado plateau, which occupies the northeastern part of the Territory; the low-lying desert plains, which occupy the southwestern part; and an intervening mountainous region. The mountains are in some cases remnants of erosion and in others faulted and tilted crust blocks. In the mountain province the valleys are narrow, but broaden away from the plateau and merge finally into a detrital plain which surrounds the comparatively small and more or less isolated rock mountains of the plains region.

Character of the detrital Formations

The detrital material varies greatly from place to place in physical character, thickness, and general field relations, according to the manner in which it was accumulated. Along stream courses and in regions formerly traversed by streams, it is composed of sand, silt, and water-worn pebbles. In the alluvial cones and slopes at the base of the mountains it is composed of angular rock fragments. In still other places it is composed principally of clay, suggestive of flood-plain or lake deposit. Owing to the arid climate of the Southwest, there are few permanent streams, and nearly all of the rock waste from the mountains accumulates at the present time as alluvial cones and slopes or as a general film of "wash" over the surface of the plains. The climate, however, has not always been arid, and the angular material usually found at the surface is no indication that like material occurs beneath. In many places wells sunk in the detritus to depths of 1,000 to 1,300 feet have penetrated beds of very diverse character. No uniformity in the kind of material or in the arrangement of constituent parts is found by which neighboring deposits can be definitely correlated. I have described at some length the composition of the detrital beds within a limited area, Salt River valley,* and have shown that during the period in which accumulation

* Willis T. Lee: Underground waters of Salt River valley, Arizona. U. S. Geological Survey, Water Supply and Irrigation Paper no. 136, 1905.

took place the streams were sometimes depositing sand and gravels and sometimes carrying away those previously deposited, while at other times the fluviatile material was buried beneath mountain wash.

Means of Correlation

The beds are unfossiliferous and for the most part are difficult of access. Filling as they do the ancient depressions, they occur chiefly in the lowlands and over undissected plains. It is only where an uplift of recent date has occurred or where some stream has cut a canyon in very recent geologic time that the deposits are well exposed. For these reasons the subdivisions of the detritus in one region can not be definitely correlated by ordinary means with those of a neighboring region. It is therefore of the greatest importance in studying these deposits that some means of correlation be found. In the course of my investigations in western Arizona, which included several overland excursions and a river trip from the mouth of the Grand canyon southward to Yuma, it became evident that an investigation of the detrital formations would be greatly aided by a physiographic study of the Colorado river. A brief summary of the physiographic history of the lower part of the Colorado is here offered.

General Description of the lower Part of the Colorado River

The Colorado river emerges from the Grand canyon at the edge of the Colorado plateau and passes in succession across a debris-filled valley, the Grand Wash trough; through a rock gorge known as Iceberg canyon; across a second debris-filled trough near Hualpai wash; through a second rock canyon cutting the Virgin mountains; across the debris-filled Detrital-Sacramento valley; through a third rock gorge—Boulder canyon—cutting the Black Mountain range; across Las Vegas basin; through Black canyon (see plate 34), and thence southward through a succession of less conspicuous rock canyons and detrital basins. In selecting its course the river seems to have shown little consideration for the easiest lines of erosion. It has disregarded mountain and valley alike. From casual observation, it would seem to have chosen about the roughest course possible. These facts are best shown in the accompanying map, plate 32.

Early geologic Events

No attempt is here made to write the early history of the region through which the lower Colorado river flows, further than is necessary to indicate the geographic conditions existing at the beginning of the

period of detrital accumulation. Briefly stated, the facts bearing on this subject are as follows:

The sedimentary formations of the Colorado plateau, still represented by a thickness of several thousand feet at its western margin, originally extended over a large part if not all of western Arzona. These were removed by erosion, the underlying crystalline rocks extensively exposed, and great quantities of andesite and rhyolite outpoured over a large part of the denuded area, to a maximum depth of about 3,000 feet. These lavas were later extensively eroded and broad valleys cut through them to a depth of 3,000 feet or more. Detrital-Sacramento valley, 10 to 15 miles wide, is the most conspicuous of these old valleys in western Arizona and was probably formed by the ancient Colorado river. Entering Arizona from southern Nevada where it is now occupied by Virgin river, this valley extends southward across the present course of the Colorado river east of the Black Mountain range (see plate 32) to the mouth of Williams river. The detrital basin still farther south, known as Great Colorado valley, through which the river flows for a distance of about 75 miles, is the southward continuation of this ancient valley.

Sometime during the period in which Detrital-Sacramento valley was formed, a displacement of several thousand feet occurred at Grand Wash fault, accompanied by the tilting of a large crust block* and the formation of Grand Wash trough. This trough was later filled with detritus, while the upturned edge of the block exposed now in Iceberg canyon was planed off by erosion. The graded surface thus formed, consisting in part of the beveled edges of upturned strata and in part of the detrital filling, now forms a shelf 1,400 feet above the river near the mouth of the Grand canyon.

In order that deposits of different age may not be confused, a brief explanation may be in place regarding the detrital filling of Grand Wash trough.

Two formations occur. The older one, consisting of angular unassorted fragments, mainly of granitic rock, varying in size from sand grains to boulders 10 feet in diameter, closely resembles the detrital masses accumulating at the present time throughout the Southwest along the bases of the mountain slopes. This formation contains a large amount of carbonate of lime near the top, occurring in part as a cementing substance in the detritus and in part as a sheet of travertine 200 feet or more in thickness and nearly free from detrital matter. The younger detrital deposit is several hundred feet thick near the mouth of the Grand canyon and consists of water-worn gravel and boulders of limestone,

* G. K. Gilbert: U. S. Geological Survey West of the 100th Mer., vol. 3, p. 54.

marble, quartzite, argillite, and granite. It is obviously of river origin and was deposited in the valley which the Colorado river had previously eroded in the older detritus.

Another deposit, probably equivalent in age to the older filling of Grand Wash trough and evidently accumulated before the Colorado river was established in its present course, is found within Detrital-Sacramento valley near the mouth of the Virgin river and consists mainly of soft beds of sand and clay containing gypsum and rock salt. The occurrence of gypsum and salt in Detrital-Sacramento valley at this point is not easy of explanation on the assumption that this valley was excavated by the Colorado river. It is possible, however, that the saline deposits may antedate the formation of the valley, and that the ancient Colorado flowed across them in eroding it, just as the river in its present position crossed them in eroding the recently formed canyons.

The suggestion that Detrital-Sacramento valley was formed by the Colorado river is strengthened by the observations of Huntington and Goldthwait,* who show that after the first period of faulting of the Colorado plateau, represented in the region here described by the displacement at Grand Wash fault, which formed Grand Wash trough, and previous to the last period of extensive faulting and the uplift of the Colorado plateau, a considerable area north of the Grand canyon in the vicinity of Toqueville, Utah, was reduced to a peneplain. The Colorado plateau was undoubtedly much lower than now and the graded plain just described near the mouth of the Grand canyon is probably a part of this peneplain. It is assumed that the planation may have been accomplished by the Colorado river flowing at that time across the plateau region north of its present course and thence southward through Detrital-Sacramento valley.

Recent geologic Events

INTRODUCTORY STATEMENTS

After the formation of the Toqueville peneplain, the second faulting and uplift of the Colorado plateau occurred, with a displacement of 5,000 feet or more at Grand Wash fault. Whatever the previous course of the river may have been, this uplift fixed it in its present course by causing it to erode the Grand canyon. West of the plateau it flowed across Grand Wash trough, thence westward through the Virgin range of mountains to the previously formed Detrital-Sacramento valley, which it evidently fol-

* Ellsworth Huntington and J. W. Goldthwait: The Hurricane fault in the Toqueville district, Utah. Harvard Collection, Museum of Comparative Zoology Bull., vol. 42, 1904.

lowed southward to the sea. After the inauguration of the Grand canyon, six distinct epochs are recognized, as follows, and more detailed examination may reveal others.

CANYON CUTTING (1)

The first epoch was one of regional uplift and active erosion in the plateau province. During this epoch the Colorado plateau rose to something like its present altitude and the Grand canyon was cut to a depth of about 6,000 feet. The area west of the plateau remained at a lower altitude, but was probably elevated to some extent, since the river lowered its channel 1,400 feet or more beneath the previously graded surface in Iceberg and Virgin canyons. The amount of erosion within the Detrital-Sacramento valley was probably correspondingly great, but little can be said of this on account of the later alluvial filling of the valley which has not been removed.

GRAVEL DEPOSITS AND LAVA FLOWS

After the canyon had been cut to its present depth near the western border of the Colorado plateau, but probably not to so great a depth farther upstream, some change occurred which caused the river to deposit sand and gravel along its course from the Grand canyon to the gulf of California. Near the mouth of the canyon gravels were deposited in a narrow valley and only small remnants of the beds remain at the present time, as those in Grand Wash trough previously referred to as the younger of the two detrital formations found there; but in the broad Detrital-Sacramento valley immense deposits accumulated to a depth of 2,000 feet or more. Similar deposits were formed in the other valleys of the Southwest and the low-lying parts of the interstream areas were built up by accumulations of angular rock debris derived from near-by mountains. Plate 33 is a photograph taken at a point where the detrital plain meets the rock slope of Hualpai mountains, and illustrates the characteristic relation of the detritus to the mountain slopes throughout western Arizona.

The extensive aggradation caused some of the rivers to wander from the valleys formerly occupied by them, and their gravel-filled channels were in some cases covered by upland wash. A notable occurrence of river gravels beneath a desert plain and the diversion of the river which deposited them has been described by the writer in a paper on the underground water conditions of Salt River valley,* in which Salt river, now flowing north of Salt River mountains, is shown to have formerly passed to the south of those mountains.

* U. S. Geological Survey, Water Supply and Irrigation Paper no. 136, 1905.

DETRITAL PLAIN IN DETRITAL-SACRAMENTO VALLEY

View shows junction of plain with rock slope of the Hualpai mountains

During this epoch of deposition numerous volcanic eruptions occurred. Sheets of basalt are included within the gravels at numerous places along the Colorado river, from the mouth of Grand canyon to Yuma. In some places they occur near the base of the gravels and in other places near the top. At the mouth of Williams river a series of eruptions occurred near the close of the epoch, the molten basalt bursting upward through the gravel filling of Detrital-Sacramento valley and spreading over its surface. One of the vents through which the basalt issued is represented by a large volcanic neck exposed in Williams canyon, and some of the lava hills in Detrital-Sacramento valley a few miles north of this canyon appear to be volcanic necks. After five sheets of basalt, each one several feet in thickness, had been formed in succession on the floor of the valley and each one buried in turn by a few feet of sand and gravel, a flood of molten rock was outpoured, forming a thick sheet, which extended completely across the valley and probably dammed the river. The undissected parts of this sheet indicate an original thickness of 800 feet or more.

A dam 800 feet high thrown across the Colorado river at this place would create slack water conditions not only throughout the entire length of Detrital-Sacramento valley, but far into the Grand canyon, and must have facilitated the deposition of river sand and gravel, which had previously accumulated in the valley to a depth of more than 1,000 feet. The altitude of the basalt sheet is essentially the same as that of the surface of Detrital-Sacramento and of the sand and gravel remnants found far above the river in the sides of Virgin canyon and at the mouth of Grand canyon.

CANYON CUTTING (2)

A second epoch of canyon cutting was brought about by some influence which rejuvenated the streams throughout the Southwest. During the extensive aggradation of the previous epoch some of the streams had wandered far from their old channels and in their now invigorated condition cut new canyons, while others reexcavated wholly or in part the old filled valleys.

The course established by the rejuvenated Colorado river was apparently influenced by the volcanic dam. An outlet had evidently been found through the Black Mountain range north of mount Wilson, and the river, abandoning its former course, remained west of this range as far south as Williams river, where it cut through the western edge of the basalt sheet and returned to its old valley after establishing a new course for a distance of about 125 miles. A more difficult course could scarcely have been selected. Instead of reexcavating its old channel

where the only hard rock to be eroded was the volcanic dam, it eroded four rock gorges, namely, Boulder, Black, Needles, and Aubrey canyons, and crossed four debris-filled basins, namely, the Las Vegas wash, Cottonwood valley, Mohave valley, and Chemehuevis valley, before returning to its former course in Great Colorado valley. The excavation of the detritus in the basins was naturally more rapid than the work in the hard rock of the ridges separating them, and the result is the curious alternation of short, sharp canyons and basin-like valleys characteristic of the Lower Colorado river.

Plate 34 is a photograph, taken in Boulder canyon, showing walls about 2,000 feet high and illustrating the youthful character of the canyons eroded during this epoch.

A satisfactory explanation for the passage of the Colorado river through Boulder canyon is yet to be found, as the mountain ridge is apparently higher than the volcanic dam supposed to have caused the diversion of the river. Several possible explanations might be offered, such as stream capture, overflow through a low pass, or a rise of the mountains across the river's course. The latter seems to be the more probable, from the fact that the Black mountains are in a region known to have been affected by recent faulting and block tilting.

DEPOSITION OF GRAVELS

Some influence not certainly known brought the second period of erosion to a close and caused the river for a second time to fill its valley with sand and gravel. The debris-filled basins in which broad valleys had been excavated while the canyons were being cut in the harder rock were again filled to a depth of about 700 feet. These deposits occur in the terraced bluffs on either side of the river more or less continuously exposed from the mouth of the Gravel canyon to the gulf of California.

CANYON CUTTING (3)

At the beginning of this epoch of erosion the river was flowing within narrow limits over an aggraded surface as it had done over a much wider aggraded surface at the close of the second epoch described (epoch 6 of the following table). Some change of condition, the cause of which is not definitely known, caused the river to again erode its bed, reexcavating for the most part the old channel, but in a number of places cutting rock gorges at one side, as at Bulls head near Fort Mohave and at Big bend in the Needle mountains.

FORMATION OF FLOOD-PLAINS

After the channel had been cut considerably lower than the present bed of the river, sand and gravel for the third time accumulated, the action

ENTRANCE TO BLACK CANYON

continuing to the present time, forming broad flood-plains. The river is continually filling its channel and changing its course, either gradually, by lateral cutting, or suddenly, by establishing some new course during a flood. The rapidity of the filling is indicated in many places where the river has cut laterally, exposing the roots of trees and shrubs now buried to a greater or less extent. Many places were noted where living arrow weeds are standing in five feet or more of silt. In other words, the surface on which the arrow weed had begun to grow had been built up 5 feet or more during the life of that shrub. The flood-plains contain numerous sloughs, lagoons, oxbow lakes, and other evidences of change in the river's course.

Correlations

The various epochs described can not at present be assigned definite places in the geologic time scale, but with a knowledge of their order which is apparently clear, and of their relative duration, which detailed investigation might furnish, the establishment of any one in the time scale would give relative place to all. Unfortunately this is not possible at present, although a probable correlation is found with the Gila conglomerate, which has been referred to early Quaternary.* This conglomerate is presumably equivalent to the great detrital accumulation of the Lower Colorado river region (epoch 6 of the following table), the correlation being based on the similarity of the beds in composition, physiographic position, and general field relations, as well as their mutual association with flows of basaltic lava.

If this detritus and the Gila conglomerate are correctly referred to early Quaternary, the order of events described places the rise of the plateau (4) and the origin of Grand canyon at or near the close of the Tertiary period, and the filling of Grand Wash trough (3), which antedates the erosion of the Grand canyon, in the Pliocene, as suggested by Mr Spurr.† It also makes the great masses of andesite and rhyolite (2) equivalent in age to the extensive lava flows of Oregon and Washington, which Professor Le Conte‡ has shown were outpoured at the close of the Miocene.

It is altogether probable that the history as here outlined is imperfect and will be modified by further investigation. It is possible that phenomena which are conspicuous in this region may not be as far-reaching as they seem to be, and that events of great importance in the recent

* G. K. Gilbert: Wheeler Survey, vol. iii, 1875; Geology, p. 540.
F. L. Ransome: U. S. Geological Survey, Professional Paper no. 12, 1903, pp. 47-57.

† J. E. Spurr: U. S. Geological Survey Bull. no. 208, p. 132.

‡ Joseph Le Conte: Am. Jour. Sci., 3d ser., vol. 7, 1874, pp. 176-178.

geologic history of the Southwest may not be here recorded. It is thought, however, that the Colorado river, flowing as it does through the midst of the region where the Quaternary deposits have such great development, is likely to furnish the best field for the study of these deposits.

TABULAR RÉSUMÉ

	Deposition epochs.	Erosion epochs.
QUATERNARY.	10. Formation of flood-plains; accumulation still in progress.	
	9.	Rejuvenation of streams; Colorado river lowers its bed about 500 feet.
	8. Deposition of 700 feet of sand and gravel.	
	7.	Rejuvenation of streams; Colorado river, flowing west of Black mountains, lowers its bed 2,000 feet or more and cuts Aubrey, Needles, Black, and Boulder canyons.
	6. Widespread aggradation and volcanic eruption; Colorado river deposits 2,000 feet or more of sand and gravel.	
	5.	Grand canyon eroded to a depth of about 6,000 feet; Colorado river flowing in Detrital-Sacramento valley.
TERTIARY.	4.	Rise of Colorado plateau and displacement at Grand Wash fault; origin of Grand canyon.
	3. Pliocene; local deposition; filling of Grand Wash trough; erosion of Detrital-Sacramento valley.	
	2.	Great volcanic activity; eruption of andesite and rhyolite.
	1.	Miocene; general degradation.

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GUADIX FORMATION OF GRANADA, SPAIN

BY WILLIAM HERBERT HOBBS

(*Presented, by title, before the Society December 29, 1905*)

CONTENTS

INTRODUCTION

The fertile *Vega* of Granada and the great plain of Guadix lie respectively off the western and northern flanks of the Sierra Nevada and are separated from each other by the much lower Sierra Harana. Level almost as a floor, on their borders their surfaces incline valleyward at low angles, producing a topographic feature most common in Spain—the filled valley out of which steep mountain ranges rise abruptly. The material with which these valleys are filled merits a fuller consideration than is here possible, but a record of somewhat hurried observations, with conclusions drawn therefrom, may be of value, since they apply to a region which has received but little attention from geologists. Von Drasche, who visited the province more than a quarter of a century ago, has furnished the best description of the deposits, a portion of which he has relegated to three formations, namely, the Alhambra conglomerate, the Block formation, and the Guadix formation.* In the Block formation, which occupies the valley of the Genil, he found Miocene fossils,

* Von Drasche: Geologische Skizze des Hochgebirgstheiles der Sierra Nevada in Spanien. Jahrb. d. k. k. geol. Reichsanst., Bd. 29, 1879, pp. 93-122, pls. vii-xii.

and, as he believed the beds to dip beneath those of notably different type on which the Alhambra is built, he gave to the latter deposits the name Alhambra formation. The Guadix formation is areally separate from both the others, though partaking of the characters of each. The map of the Spanish Geological Commission* shows the greater part of the three formations as diluvial, and the resemblance of the Block formation in particular to a glacial deposit is certainly most striking. Until the writer had examined numerous localities he was compelled to adopt the view that local glaciers from the Sierra Nevada had deposited the ma-

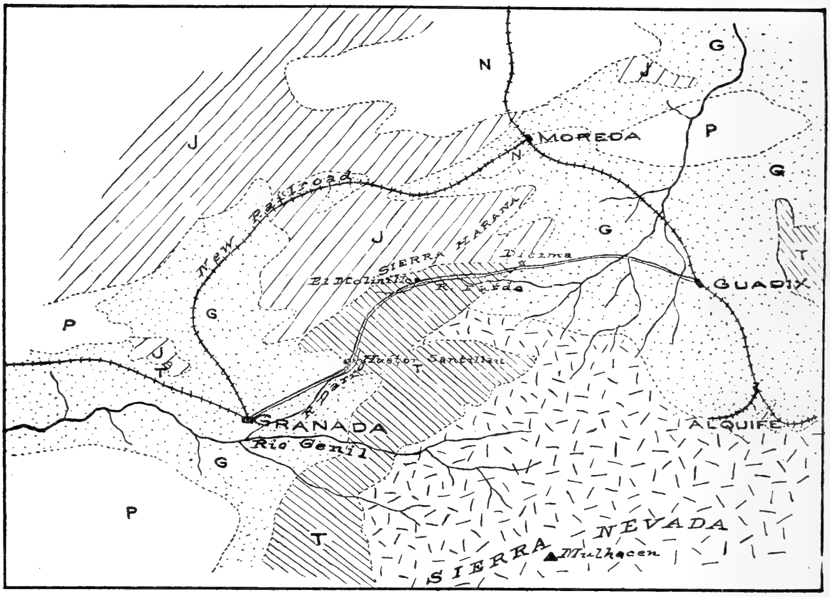

FIGURE 1.—*Map of the Guadix and neighboring Formations.*

Modified from the map by the Spanish Geological Commission. The mass of the Sierra Nevada is composed of crystalline schists of Silurian or greater age. *J*, Jurassic; *T*, Triassic; *N*, Neocene; *P*, Pliocene; *G*, Guadix formation.

terial, and it appears that every geologist who has studied the district has given prominence to a supposed glacial origin for the formation. Moraines in the valley of the Genil were even described by Schimper.† Bertrand and Kilian ‡ state that the lower layer of the Block formation at Talara contains calcareous pebbles which are polished and striated, and they quote Taramelli and Mercalli as holding this opinion of a

* Sheet no. 52, Granada, second edition.

† Schimper: Voyage géologique botanique au Sud d'Espagne, 1849.

‡ Bertrand et Kilian: Études sur les terrains secondaires et tertiares dans les provinces de Grenada et de Malaga. Mem. de l'Acad. de Sciences de l'Institut National de France, t. xxx, p. 520.

glacial origin. Von Drasche, while explaining away the moraines of Schimper, describes a great block scratched and polished which was found near the Camino de los Neveros.*

Description of the Guadix Formation

THE BLOCK FORMATION

For a study of the Block formation one has only to go from the Alhambra of Granada, past the *Cemiterio,* into the valley of the Genil. Immediately after passing the cemetery on the crest of the divide between the Rio Darro and the Rio Genil the change in the deposits is apparent. From a loosely consolidated deposit of gravel containing large and small, well rounded pebbles, mainly of a single type, with maximum size a few inches in their longest dimension, one here encounters a deposit the pebbles of which are dark colored diorites and gabbros, together with garnetiferous schists, fissile mica-schists, and many other crystalline types of rock foreign to the immediate neighborhood. The size of the pebbles also varies from a fraction of an inch to boulders whose dimensions must be measured in feet. There is, further, to be observed a noteworthy frequency of faceted boulders which in shape are not to be distinguished from those found in a bank of glacial till. Many blocks are polished, but the writer was unable to discover any on which glacial scratches could be made out. On the dump from a mining shaft sharply faceted blocks were found in abundance which are with little doubt derived from the lower layers of the formation, and these are polished in a noteworthy manner. The surface of these blocks gives, however, the impression of slickensides rather than of glacial polish, and, in view of the description by von Drasche of such forms in the Sierra Nevada, any other explanation would seem to be superfluous.† The source of the blocks is clearly the slopes of the Sierra Nevada on which the Genil has its source.

THE ALHAMBRA FORMATION

The Alhambra formation occupies the valley of the Darro, which has its rise not in the crystalline rocks of the Sierra Nevada, but in the Triassic dolomite of the Sierra Harana. The uniformity in petrographic type of its pebbles and their smoother contours, find in this their explanation. The thickness of the Alhambra formation can be little short of

* Loc. cit., p. 121.

† "Diese Schiefer sind ungemein mürbe; ein Hammerschlag auf einer grossen Block lässt denselben in ein Haufwerk von krummflächrigen Flatschen zerfallen, die auf der gewölbten Fläche stets eine Art Seidenglanz zeigen. Es scheint als ob die ganze Schiefermasse in sich selbst verrutscht wäre."

1,000 feet, mainly a conglomerate having distinctly water-worn pebbles which vary from a fraction of an inch to six inches or more in length. Interbedded within the formation are layers of fine sand and loess-like material which changes most abruptly to the conglomerate. In the finer material stratification shows plainly, and, while generally horizontal, dips as high as 25 degrees occur; but these dips are in the narrow portions of the valley and are apparently uniformly in the direction of its bottom.

In ascending the valley of the Darro along the old post road from Granada to Guadix, one sees great thicknesses of the loess-like material, and at other times merely thin layers a fraction of an inch in thickness may be followed for many rods along a horizontal plane within the conglomerate. Not infrequently lenticular forms are noticed in the section. A little above the village of Huétor-Santillan the Alhambra formation comes into contact with the Upper Triassic dolomite of the Sierra Harana to the north of the road. The Darro valley has now narrowed to such an extent that the same dolomite soon appears upon the other side of the valley as well and the Alhambra formation presently comes to an end. Its steeper dips toward the valley are here noticeable, and the weathering of the dolomite is most instructive in considering the origin of the Guadix formation. Rising in steep slopes, the dolomite takes the form of beetling crags whose divisional plains have been largely determined by joints, while at the base of the cliffs is found an aggregation of larger and smaller blocks already arranged imperfectly in trains along the bottoms of small gullies or barrancas. The first heavy shower will carry a portion of these blocks down into the Darro valley, rounding the angles on the soft material. An observation of von Drasche, made to the east of the divide, is that the larger blocks are generally found near the borders of the formation.

THE GUADIX FORMATION OF VON DRASCHE

Passing over the divide between the Darro and the Farde near El Molinillo and descending into the valley of the last mentioned stream, after passing Diezma we obtain a view of the broad plain of Guadix, which stretches away for 25 miles to the base of the Sierra de Baza and appears as level as a floor. In this deposit of soft material the Farde has cut broad valleys with level floors and steep walls, revealing abundant sections of the material, which has characters in many respects the same as those found in the valleys of the Darro and Genil. It is, however, as a rule finer in texture, with larger proportions of loess. This loess is locally filled with roots and brush ("Noah's brush heap"), is yellow in color, and altogether quite similar to the loess of the upper Mississippi valley. Throughout the loess is very perfectly jointed on vertical

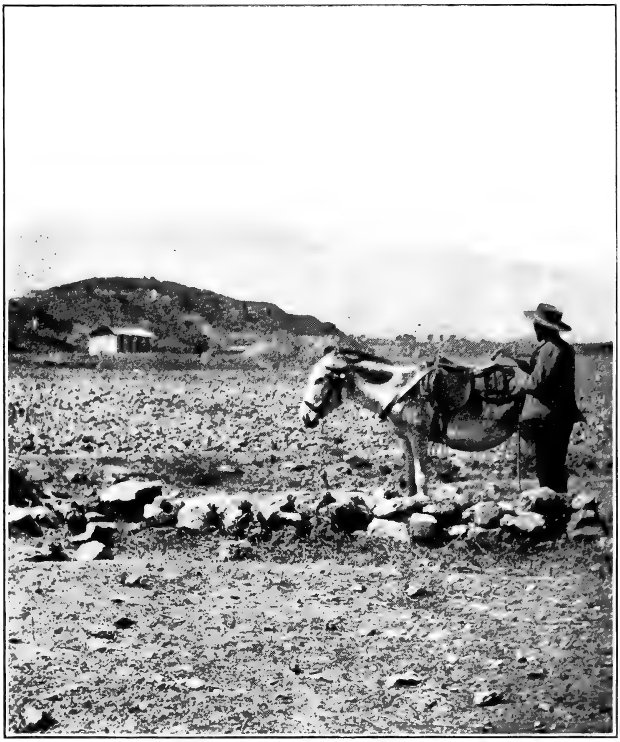

FIGURE 1.—JUNCTION OF THE GUADIX FORMATION WITH THE SIERRA NEVADA AT ALQUIFE

Mountain of hematite in middle distance

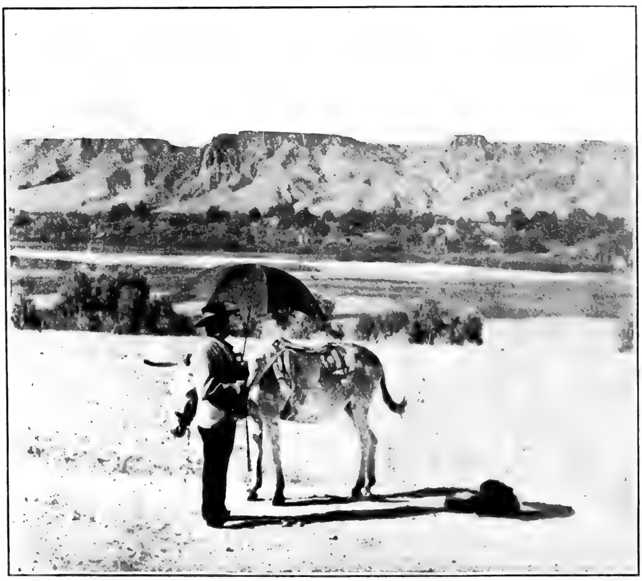

FIGURE 2.—"BAD LANDS" TOPOGRAPHY IN THE VALLEY OF THE FARDE

CHARACTERISTIC TOPOGRAPHY OF THE GUADIX FORMATION

planes. Within the finest loess one sees in vertical sections lenticular areas of finer or coarser pebbles. Small aprons of talus at close and fairly regular intervals border the river walls at their bases (plate 35, figure 2).

Seen from the heights about the valley, not only is the surface of the formation notably horizontal, but several stages of lower and parallel planes produce sharply delimited shelves wherever the river has opened the formation in sections. The upper layer and some of the lower ones show a rich brown color, and on nearer approach are seen to be colored with soft hematite. As one looks to the southward beyond the formation toward the distant Sierra Nevadas, one sees rising at their base the black mass of the mountain of hematite at Alquife,* and it is difficult not to ascribe a common source to it and to the hematite of the Guadix formation in an earlier ferruginous deposit situated higher up and in the Sierras themselves. The color effect in the general view from below Diezma is unusually fine, the hematite layers standing out in the dissected valley floor like pencil lines, with the black iron mass of Alquife and the white dolomite of the Alcohorra (each capped by a Moorish castle) sharply outlined against the gray background of the Sierra Nevadas. Where the Farde has cut its broad valley, patches and strips of green appear beneath the diversified and picturesque "bad land" topography which surrounds them. The labyrinth of loess columns, eaten into by the sudden rains, have been excavated locally to furnish homes for a large proportion of the peasant population in the district (see plate 36). Plate 35, figure 1, shows the abundance of irregular boulders upon the surface of the formation where it borders upon the Sierra Nevadas.

Origin of the Formation

The Guadix formation appears to be largely a torrential deposit of material derived from the neighboring Sierras, with local characteristics restricted to the individual valleys of the Genil, Darro, and Farde, and dependent on the rock material which is in place near the headwaters of those streams. The material is coarser near the borders of the formation, while loess and floating material, such as roots and brush, are more characteristic of the central and presumably quieter areas. To account for the almost perfect horizontality of the beds within the central areas, it is necessary to assume the former existence of at least temporary lakes within the valleys, while the lenticular forms of the pebbly material in the sections indicate that streams once coursed over the floor of material below. Some part has undoubtedly been taken by the wind in depositing the formation, since it is active today in transporting the lighter ma-

* See an article by the author treating of the iron mines at Alquife.

terial, but its rôle would appear to be secondary to the cloudbursts and the resulting torrents of the rainy season.

Such an alternation of conditions as is indicated by the material of the Guadix formation is found today only in arid regions of high relief, where the rare but violent storms develop the torrent and the *playa* lake, and where the wind plays an important part in transporting the surface material. The climate within the province of Granada is today semi-arid—the fertile *Vega* of Granada being an oasis, which only accentuates the surrounding aridity.

Age of the Deposits

As already indicated, Miocene fossils have been found in the Block formation of von Drasche, and as has here been shown, torrential deposits are forming today in the valley of the Darro and elsewhere. It is probable that the Guadix formation includes beds extending without noteworthy interruption from the Miocene to the present. That similar conditions have prevailed from even earlier times might be inferred from the occurrence of a conglomerate of Triassic age at the base of Alquife hill, which is located on the exact border of the Guadix formation and at the foot of the Sierra Nevadas. This conglomerate includes angular boulders of iron ore whose dimensions are sometimes measured in feet.*

Torrential Deposits of southern Italy

Deposits remarkably similar to those of the Guadix formation border much of the mountainous coast of the Italian peninsula and Sicily. Above Reggio, in Calabria, blocks of granite two feet or more in their largest dimensions are found associated with similar blocks of several other crystalline types as lenticular forms within deposits of sand, gravel, and finer material, all of which has clearly been derived from the Calabrian Apennines immediately to the east. The bedding of these deposits is for the most part nearly horizontal, though angles as high as 30 degrees were observed. The topography of these deposits, wherever dissected, is that of the "bad lands"—the type for rain erosion. Such deposits may be seen to even better advantage to the westward of Messina, in Sicily, on the road to Castellaccio.

The intermittent streams (*torrenti* or *fiumare*), which are so characteristic of southern Italy, have dissected the deposits. These valleys are wide at their mouths, with broad, flat floors, which ascend at extremely low but ever increasing grades toward their heads, where the slope rises abruptly like a *wadi* to form an amphitheater. On these

* William H. Hobbs: Mining in Spain. The Mining World, vol. 24, 1906, pp. 109-110.

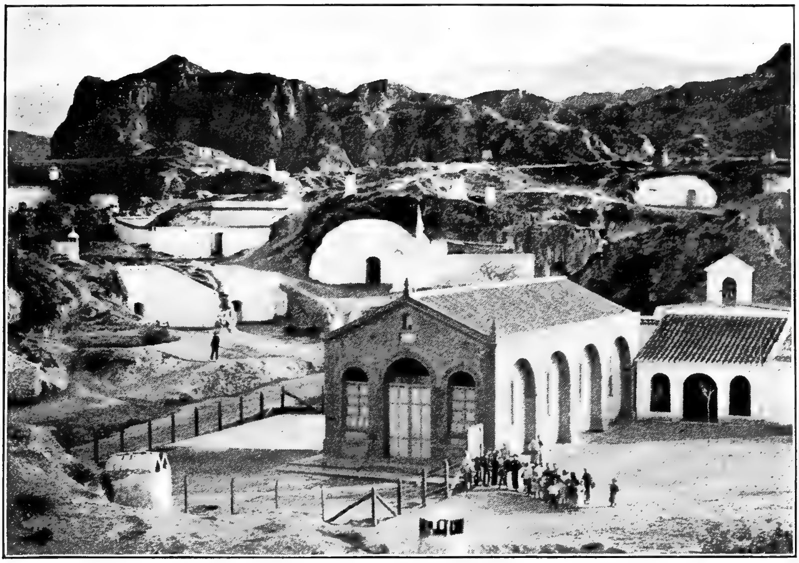

Figure 1.—Cave Dwellings in the Guadix Formation at Barrio de Santiago

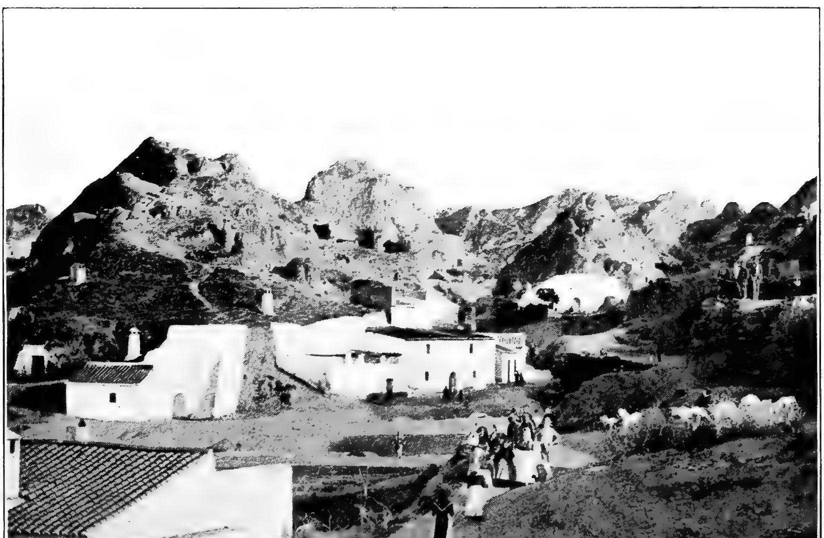

Figure 2.—Rain Erosion Forms at Barrio de Santiago

CHARACTERISTIC TOPOGRAPHY OF THE GUADIX FORMATION

slopes are often found the steep pinnacles with pebble cappings so characteristic of rain erosion. Other deposits and erosional forms were observed about Taormina and are well shown from the summit of Mola.

In the summer season the "fiumare" are dry, the pebble floors being generally utilized as highways of travel; but after the rains they become roaring torrents, which suddenly rise and as suddenly subside. At Cosenza, in Calabria, the writer was fortunate in witnessing the transformation of the Busento (the ancient *Buxentius*) by one of the sudden cloudbursts characteristic of the region. Crossing the river by the famous Ponte Alarico in the face of an impending shower, the broad river floor showed a mere thread of water. When the storm had burst the steeply sloping Corso of the city became transformed into a swift current bordered by waterfalls where the steep side streets entered. Within a half hour the storm had passed, but the Busento was swollen to a roaring torrent which filled its bed from bank to bank. A few hours later it presented almost the same appearance as before the rain.

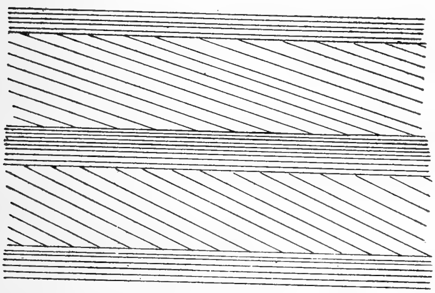

FIGURE 2.—*Type of Cross-bedding.*

Observed in the torrential deposits near Pontegrande, in Calabria.

All about Cosenza are found torrential deposits, including round pebbles and boulders, not unlike the Alhambra conglomerate of Granada. Nearly identical deposits were studied at Rossano and at Pontegrande, near Catanzaro, in Calabria. At the last mentioned locality the deposits can be little short of 1,500 feet in thickness, if they do not exceed that figure. The boulders included are of many petrographic types and often exceed a foot in diameter. Between markedly horizontal layers revealed by the finer material, cross-bedding of a type often seen in ancient sandstones is well displayed (figure 2). In this type we find between thick horizontal layers intercalated beds in which the bedding makes a nearly uniform but relatively large angle with the layers which inclose it.

At Rossano the torrential deposits are locally faulted in the manner shown in figure 3. Through these deposits the crystalline formations occasionally project on steep walls. High up the valleys toward the crests of the older rocks the generally horizontal bedding is locally replaced by steeply dipping layers, which, like those observed in Granada, incline toward the valley. Angles as high as 45 degrees have been observed. Where deep dissection has been produced by the "fiumare," the steep walls of loosely compacted material become during the rainy season

saturated with water until one of the earthquakes so characteristic of the province sets loose a large mass to slide down and be soon dispersed by the torrent below. The banks of many fiumari present great scars, the freshness of whose surfaces furnishes an indication of their relative age. On the fiumare Oliveri, between the Calabrian village of Aiello and the Tyrrhenean coast (a distance of about 10 kilometers), a number of these great scars were seen, the largest caused by a landslide during the past year. In this category must be placed also the mass of soft rock (which has been estimated at 7,000 cubic feet) which was precipitated from the castle rock upon the town itself by the earthquake of September 8, 1905.

The torrential deposits which border southern Italy between the mountains and the sea appear to be in part of Quaternary age (especially those bordering the straits of Messina); they are also in part Recent, and in part they are pre-Quaternary. Cortese, who has furnished the best report upon the region,* ascribed much of the Recent and some of the

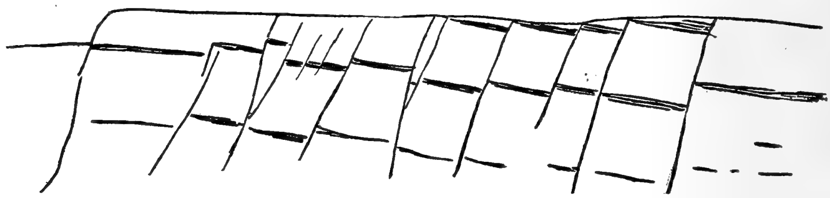

FIGURE 3.—*Faulted torrential Deposits at Rossano, Calabria.*

Quaternary deposits to a fluviatile origin through the agency of the torrenti, and stress is laid upon the difficulty of delimiting the several formations. The occurrence of these deposits in distinct pianos or shelves on the seaward side of the Apennines he explains by the existence of such topographic forms in the surface of the underlying crystalline terrane; and with this view the writer is in full accord.†

Within the extensive arid regions of the western United States the present-day importance of the torrent and the desert lake in filling the valleys and fashioning the topography has been generally recognized by the geologists who have studied the region.

Probable torrential Origin of many Sandstones and Conglomerates

A terrane as heavy and as extensive as the Guadix formation, when buried beneath later deposits and cemented into sandstone or quartzite,

* E. Cortese: Descrizione geologica della Calabria. Memorie descrittive della carta geologica d'Italia, vol. ix, 1895, pp. xxviii and 310, map and 4 plates.

† See the colored plates of the work cited for the topographic character of the *piani* and figure 19*a*, on page 185, for a hypothetical section.

must figure largely in the formations of the district when these have been exposed upon a later erosion surface. Such a formation should be bordered by a fringe of coarse breccia-like conglomerate giving the impression that it is a basement layer, and perhaps also having a basement layer of the same or similar material. It should be characterized by included lenticular areas of coarser or finer material and by layers of fine material in sharply defined films and plates which reveal its bedding. If undisturbed from its original attitude, its bedding should be generally horizontal, though with a gentle centrally directed inclination upon its borders, resembling in this the initial dip of a marine formation. Locally, at least, it may show a type of cross-bedding like that represented in figure 3, which, though often observed in ancient sandstones, is not adequately explained by the changing currents along a marine shore.* In its finer-textured portions a rectangular jointing will be likely to be found characteristic, and minor faulting dating from a period when the material was only slightly compacted is possible (see figure 3). The great variety of rock type, the range in dimensions of included pebbles and boulders, and the frequency of faceted forms among them may suggest an origin of the formation through glaciation, as has been true of the massive conglomerates of the original Huronian of Canada.

Having in mind the fact that arid conditions prevail today over about three-fifths of the earth surface, the study of the torrential, playa, and eolian deposits, which are characteristic of desert regions, must be brought into consideration before an adequate explanation can be found for the masses of sandstone and conglomerate, 1,000 to 1,500 feet and more in thickness, which exist within the ancient rock formations of the globe. It is but natural that the first explanation of these formations should have been based upon geological processes which are most familiar—those concerned in the erosion of the land areas under humid conditions with deposition along the ocean littoral. Marine sandstones should, however, be relatively thin; for it would appear that during a transgression of the sea on the land the formation of sand should be limited to a depth not far below the wave base—a depth measured in tens rather than in hundreds or thousands of feet. To meet this difficulty, the theory of Hall, that depression is in areas of deposition adjusted to the material deposited, has been greatly strained.

The dominance of ripple marks and the paucity of marine fossils just where marine life should have been most abundant are facts difficult to

* Such a structure is shown in great perfection over considerable areas by the Cambrian sandstone exposed in the picturesque "Dalles" of the Wisconsin river near Kilbourn City, Wisconsin.

explain on the theory of marine origin for the great sandstone formations. The enormous expanse of sandstone formations fits better to a desert than to a marine theory of origin along the ocean borders. In the Triassic or Newark formation we find beds of clay of clastic origin lacking marine fossils, together with conglomerates, moraine-like deposits of debris, great beds of sandstone and conglomerate, colored clays, and beds of salt and gypsum, all alternating with marine sediments. Within the sandstones are found rain-drop impressions as well as footprints of animals, but without the animals themselves.

In the Tertiary deposits of the Paris basin there is found such an alternation of marine sediments filled with mollusks, with clay, gypsum, and sandstone, including the bones of land animals, that it is little wonder Cuvier was impelled to adopt his theory of earth cataclysms to explain them. Just such alternations are, however, characteristic of the deposits in desert regions, where the torrent and the playa lake are found, where the surface deposits are continually shifted by the wind, and where the barrier from the sea is at times broken down. At such times the land fauna is either driven away or destroyed, and in the latter instance a "bone bed" is entombed beneath marine deposits which later may come to the light and their territory be again invaded by a land fauna.

As regards the more ancient sandstone formations, the frequent occurrence of an abundance of angular feldspar fragments to form an arcose indicates a secular disintegration of granitic rocks under essentially arid conditions. Such an explanation has been applied by Pumpelly* to the Greylock district of Massachusetts, and the writer has found striking illustrations of such deposits from near the Massachusetts-Connecticut interstate boundary.† The recent papers by Walther,‡ Passarge,§ and Davis‖ indicate that the part the desert has played in geological history is to receive greater attention in the future than it has in the past.

Acknowledgment

The writer desires to acknowledge his indebtedness to M. Pelsmacker, the Belgian consul at Granada, who is both a mining engineer and a competent geologist, and whose familiarity with the geology of the province has been of great assistance to the writer in his study of the district.

* R. Pumpelly: Monograph xxi, U. S. Geol. Survey.

† Best seen on the summit of Collins hill, near New Milford, Mass.

‡ J. Walther: Das Gesetz der Wüstenbildung. Berlin, 1900.

§ S. Passarge: Die Kalahari. Berlin, 1904.

‖ W. M. Davis: The geographical cycle in an arid climate. Jour. Geol., vol. xiii, 1905, pp. 381-407.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CRETACEOUS SECTION IN THE MOOSE MOUNTAINS DISTRICT, SOUTHERN ALBERTA*

BY D. B. DOWLING

(Read before the Society December 29, 1905)

CONTENTS.

INTRODUCTION

The Cretaceous which underlies the Canadian plains is so nearly undisturbed that no great difficulty has been experienced in tracing over large areas the different horizons found. Near approach to the Rocky mountains is, however, accompanied by serious foldings in the strata, so that the foothill region requires detailed study before the formations can be accurately mapped. The discovery of coal at several horizons renders this folded area of interest on account of the many chances that the lower horizons bearing the best grade of coal may there outcrop.

The reported discoveries of petroleum in the southern portion of Alberta were given great publicity and the producing fields of Colorado were cited as examples of what might be expected at almost any point along the front of the Rocky mountains. The desirability of a study of this region is thus quite evident, and last season one party was located in the foothills south of the main line of the Canadian Pacific railway. The work was intrusted to Mr D. D. Cairnes and considerable progress was made in his examination. To correlate the several formations, fossils were collected, but many are of plants which have not been studied yet.

* Published by permission of the Acting Director of the Geological Survey of Canada.

Two of the greater folds reveal the limestone beneath and several sections were made of the total thickness of Cretaceous strata. As my own

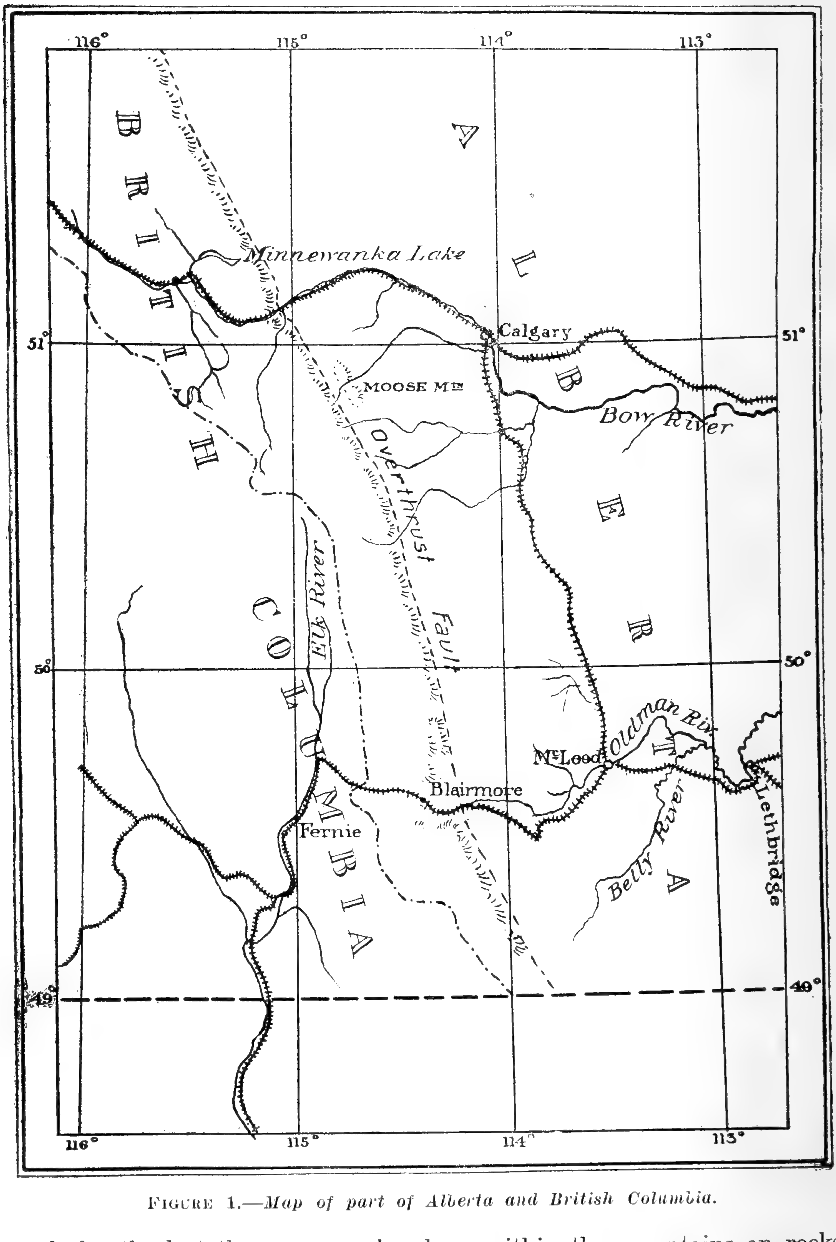

FIGURE 1.—*Map of part of Alberta and British Columbia.*

work for the last three seasons has been within the mountains on rocks of the Kootanie series, I can with some certainty correlate them with

some of the lower beds found in this section. Previous to this time it seemed doubtful that any exposures of the Kootanie could be found east of the mountains or that the correlation with the Cascade formation of Montana or that in the Black hills called Lakota could be safely assumed. This seems less risky if the Kootanie occurs in the section here discussed.

Provisional Subdivisions of the Sections

As the fossil remains have not been critically studied, the subdivisions I have made are provisional and the succeeding remarks are put forward with the hope that criticism and discussion may reveal errors or misapprehensions on my part which if left unnoticed might prejudice Mr Cairnes in his study of the area:

Provisional.	Dawson's section.	Cairnes' section.	Type of fossils.
Edmonton.	Saint Mary river.	Sandstones with coal seams.	Brackish water and plants.
Bearpaw.	Pierre.	Shale, 250 feet. Sandstone, 50 feet. Shale, 450 feet.	Marine.
Judith river.	Belly river.	Sandstone, 750 feet. Colors—green, blue, yellow, and red.	Fresh water.
Claggett.	Lower dark shales.	Banded sandstone and clays, 250 feet.	
Eagle.		Light colored sandstone, 50 feet.	
Colorado.		Sandy shales grading down to black shales, 750 feet.	
Dakota.		Light colored hard sandstone conglomerate at base, 150 feet.	
Kootanie.	Kootanie.	Dark sandstone and shale, with coal seams.	Plants, conifers, and ferns.
Fernie.		Dark brown to black shale, 225 feet.	
Carboniferous limestone.			

Carboniferous Limestone

The lowest member of the above section, the Carboniferous limestone, was by Dr G. M. Dawson* made to include the black shales resting on

* Annual Report, Geological Survey of Canada, vol. i, p. 104B.

them; but the finding by Mr Cairnes of a few Belemnites excludes them from the Paleozoic. The limestone here formed the floor on which the Mesozoic sediments were laid down; but in the many contacts observed at various places throughout Canada the floor evidently consisted of the overlapping edges of several formations. The crustal movements, however, not having been severe, the unconformity is not conspicuous and is indicated mainly by the different age of the beds in contact and the varying amount of the time interval so indicated.

To the west of this locality there are two troughs in the mountains that show Mesozoic rocks resting on a series of red sandy shales and buff quartzites that are above the Carboniferous limestone and seem to occupy a horizon similar to that of the Minnelusa and Opeche formations of the Black hills. These probably represent the top of the Carboniferous or early Permian. East of the mountains the exposures on the Peace and Athabaska rivers and in Manitoba show Cretaceous resting on Devonian. Southward in the Black hills the section is apparently complete.

Fernie Shale

This formation, which is represented by 225 feet of dark brown to black shale, seems to represent the eastern margin of much thicker deposits of marine origin occupying a similar position in the mountain troughs to the west. The finding of Belemnites of apparently similar species in both helps the correlation. The formation is traced both north and south along the Cascade and Bow River trough for a long distance and varies somewhat in thickness. On the Cascade river, near the outlet of a stream from Minnewanka lake, the section measured 1,600 feet. The top of the formation is here difficult to define, as the Kootanie formation in the lower part consists of brown shales and thin bedded sandstones. Few fossils were found in the exposures, with the exception of the Belemnites above mentioned, but in a shallow trough at the east end of Minnewanka lake (formerly Devils lake) Mr McConnell discovered a bed rich in marine fossils. These have been described by Doctor Whiteaves.* They show a remarkable similarity to the fauna of the lower part of the Queen Charlotte Island series, the "lower shales" of Dawson. This series was incorporated by him in the Cretaceous, but the general Jurassic aspect of most of the fossils was remarked by Doctor Whiteaves, although he accepted the stratigraphic position assigned by Dawson. The work of Messrs Stanton and Martin† on the Jurassic of Cooks inlet and the Alaska peninsula seems to show conclusively that this fauna belongs well down in the Jurassic. Evidently the fossils from the lower

* "Contributions to Canadian Palæontology," vol. i, part ii.
† Bull. Geol. Soc. Am., vol. 16, p. 402.

shales are from two formations and the Queen Charlotte Island series, if again studied, might allow this subdivision to be made.

Souhward the formation has been traced in the mountains through a succession of fault blocks to the Elk River coal field and is the series there called by Mr McEvoy the Fernie shale. Few fossils have been collected from the southern portion, owing probably to the fact that the outcrops of these soft beds are partly concealed, but from near the mining town of Fernie Belemnites and Ammonites were obtained. One of the latter is described by Doctor Whiteaves as *Cardioceras canadense*.* This would appear to be Jurassic, as the formation is continuous and bears the same relation to the coal-bearing Kootanie series above, the horizons should be but little below that from near Minnewanka lake, which is correlated with the lower shales of the Queen Charlotte islands. These latter, as noted above, are declared to be well down in the Jurassic.

The deposits at Fernie consist of 500 feet of sandy argillites at the base, with 1,060 feet of black and brownish shales above. Eastward through the Crows Nest pass the series decreases, and at Blairmore, near the edge of the mountains, there is only 700 feet. Projecting these beds eastward by assuming a somewhat uniform decrease, it would seem that they may form a small sheet eastward from the mountains, the edge approximating a line southeast from near the Moose Mountain locality.

Kootanie

Dark, coarse sandstone, with brown shales and coal seams, 375 feet.

This sandstone coal-bearing member of the Kootanie is the representative of thicker measures in the type locality, and all the fossils obtained, on which the discussion of the age of the formation was based, were obtained from within its boundaries. The base of the formation consists of hard sandstones, which are easily traced, making a convenient horizon marker for the base of the formation. Above the coal seams there is a persistent horizon of conglomerate, and in the sandstones succeeding it plants of the Dakota type have been found, so that the conglomerate band for practical purposes is taken as the top of the formation. The thickness on the Elk River escarpment of this formation measures 5,300 feet. Eastward in the Blairmore district, just within the mountains, it has decreased to 740 feet. North, near Banff, it is 3,900 feet, but in the section under discussion there is but 375 feet included between beds bearing characters similar to the limiting members within the mountains. It would thus seem that the formation might not extend much farther to the east in this latitude; but to the south

*Ottawa Naturalist, vol. xvii, p. 65.

there is a better chance of some of the beds reaching those of the Cascade formation of Montana, which are correlated by plant remains with it.

This formation is of great economic importance, owing to the rich coal deposits contained within its beds. On Elk river there are 22 seams, aggregating 216 feet of coking and steam coal. At Blairmore 21 seams of a total thickness of 125 feet, and at Moose mountain there are 7, two of which are workable, having 8 and 7 feet of coal respectively. In Montana, where the formation seems thinner, one workable seam is found near the top of the formation. In the Black hills, coal-bearing beds which seem to occupy eroded valleys in the Jurassic are reported.

Dakota

Light colored, hard sandstones, with conglomerate at base, 150 feet.

As no fossils were here detected, these sandstones are supposed to represent the horizon that is above the conglomerates of the basin within the mountains, and, as the formations originally constituted a continuous sheet, the supposition will probably be borne out by the subsequent finding of fossils. On the north branch of the Oldman river Doctor Dawson observed a bed of ash rock at the top of the formation. This was again more extensively developed near the Crows Nest pass. The Moose Mountain locality seems to be beyond the limits of this volcanic ash and the formation passes to a black shale above, which is probably Benton. In the locality just mentioned Doctor Dawson collected from the sandstones just below the ash bed plant remains similar to the Dakota flora, and on the middle branch of the north fork, Oldman river, from a horizon above the conglomerate beds, a series of plants which have affinity with both the Dakota and Kootanie—that is, of five species recognized a fern and two conifers occur in the Kootanie and one of the two species of dicotyledons was originally described from the Cretaceous of Vancouver island generally placed at about the Dakota horizon.

There is thus in the thicker part of the formation a trace of the change from the flora of the Kootanie to that of the Dakota.

As marine beds, mostly shales, holding Benton fossils are found above the ash beds at the localities just cited, and also occur in the Moose Mountain section, the sandstone series beneath should represent the same deposition, but of greatly diminished thickness in the latter locality. The diminished thickness of the beds in the Moose mountain point to a possible time hiatus between the top of the Kootanie and the base of the Dakota. Attention to this is also drawn by Mr Ward in the Black Hills section. The complete section is probably to be found only in the Rocky mountains. Fresh-water conditions during this period prevailed in Dakota and Montana and probably along the western margin, but northward

on the Athabaska river the Tar sands, representing a period contemporaneous with the Dakota of Manitoba, have a marine fauna.*

On the Elk River escarpment shore conditions prevailed for a considerable time after the inauguration of the Dakota period, and the formation is represented by a great thickness of conglomerates and sandstones.

Colorado

By eliminating the recognized formations above, there remain some 725 feet of a succession of sandy shales and shale bands grading downward in the section to black shales which can be taken as representatives of the Colorado formation. As it is partly littoral, its thickness does not seem to represent the deposition of the entire period, and thus in the top of the Dakota is probably included the marginal deposits of the advancing shoreline, concealing a probable time hiatus at the top of the Dakota.

Montana Formation

Following the succession as delineated by Messrs Stanton and Hatcher in northern Montana, a conspicuous light colored sandstone, 50 feet in thickness, may be called the Eagle formation. Above this 250 feet of banded clays and sandstones would be the Claggett formation or "lower dark shales" of Dawson's southern Alberta section. A sandstone formation above it, with a thickness of 750 feet, holding the only fresh-water fossils found in the section, would be the Judith River formation. This latter does not contain in this locality an extensive land flora and there are but slight indications of possible coal seams. The shales above the sandstones are very much like those hitherto called Pierre, and the only marine invertebrates, with the exception of those from the Fernie shales, collected during the past season are from these upper shales and are typical Pierre.

On the Bow river, east of Calgary, the Pierre described by Doctor Dawson includes a sandstone series about 50 feet in thickness, which is again found more largely developed on the Red Deer river north. In the foothills this sandstone is 200 feet in thickness along the Bow river and is sometimes conglomeritic, but decreases in thickness toward the south and is only about 50 feet on Sheep creek. It consists of three well marked bands of sandstone, which maintain their character through this range and occupy a position in the upper third of the formation. The Pierre described by Mr J. B. Tyrell on the North Saskatchewan contains intercalated sandstone beds at all horizons from the top to near the base, and all bear marine fossils of Foxhill type; so that as a formation

* Ottawa Naturalist, vol. xii, p. 37.

the Foxhill is submerged in the Pierre. As Mr Stanton wishes to call the shales above the Judith river the Bearpaw formation, it is doubtful whether the Saskatchewan deposits should be included, but in the section here discussed the name could be used, as it is quite similar to the formation in Montana.

Edmonton Series

The sandstones capping the Bearpaw shales contain a few brackish water shells and many plant remains. The thickness of the brackish water formation as distinguished from the fresh-water beds of the Tertiary was not ascertained. The Edmonton series represents the top of the Cretaceous and includes the lower part of the Saint Mary River series, which is a part of the Laramie.

Summary

The Jurassic sea at its latest stage invaded the area of what is now the Rocky mountains in a narrow depression. The transition beds at the base of the Cretaceous were next laid down. The floor over which the Cretaceous was spread consisted of various formations, forming an overlapping series increasing in age toward the northeast. The early Jurassic sea was narrow, or at least extended not far east of what is now the Rocky Mountain area. Land conditions prevailed throughout portions of the Kootanie, and the greatest deposition of detrital matter and remains of an abundant flora occur in the same depression. In the later part of the Kootanie time the deposits extended possibly southeastward to the Black hills. This period is closed by a depression in the central part of the continent, and the marginal beds of the sea, which then advanced, form the Dakota sandstone on the eastern margin. On the west similar deposits seem to be continued from the Dakota, by way of the Black hills, to the mountains, but both north and south there are evidences of salt-water deposits about this time. The Colorado formations here indicate in the upper members proximity to a western shore. The Montana formations are very similar to those near the Judith river. Land conditions then close the Cretaceous time, but intermittent encroachments of the sea continue to the beginning of the Tertiary.

Note by the Author

Since the paper was sent to the printer, determinations of the fossils have been received, proving the Kootanie age of the lower member, but bringing the Edmonton of the provisional list down to the Judith river. The revised section will be found in a forthcoming report by Mr D. D. Cairnes.

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CRESCENTIC GOUGES ON GLACIATED SURFACES*

BY G. K. GILBERT

(Read before the Cordilleran Section of the Society December 30, 1905)

CONTENTS

INTRODUCTION AND DESCRIPTION

Associated with striæ and other evidences of glacial abrasion are certain types of rock fracture. These have been classified and described by Chamberlin in his "Rock-scorings of the great ice invasions."† The three principal types are chatter-marks, crescentic cracks, and crescentic gouges. All of these are so associated with glacial sculpture and striation as to indicate that they are of glacial origin. They all occur characteristically in sets, the members of each set succeeding one another in the direction of ice motion and each individual marking having its longer axis athwart the direction of ice motion.

Chatter-marks and crescentic gouges have a common character, in that each is characteristically a shallow furrow with crescentic outline. In crescentic gouges the convexity of the crescent is usually turned forward;‡ in chatter-marks it is usually turned backward. Chatter-marks are closely associated with grooves engraved by boulders. Crescentic gouges are not thus associated; they frequently occur on surfaces exhibiting no other marks of glaciation except fine striæ and polish.

*Published by permission of the Director of the U. S. Geological Survey.

†Seventh Ann. Rept. U. S. Geological Survey, pp. 218-223.

‡In this paper the words *forward* and *downstream* are used to indicate the direction toward which the glacier moves or moved, and *backward* and *upstream* to indicate the opposite direction.

The features called crescentic cracks are vertical fractures of the rock without the removal of fragments. They are usually curved in plan, with the concavity turned forward. Their orientation thus relates them to the chatter-marks, but they are independent of grooves.

An approximate understanding of the glacial chatter-mark is easily reached, because the phenomenon is intimately related to the chatter-mark of the machinist, from which it is named. The plowing of a groove in a brittle substance is not a continuous process, but is accomplished by making a series of fractures, each one of which separates a fragment of the substance. Each fracture is preceded by a condition of strain and stress, and these are relieved by the fracture. The resistance to the grooving tool is thus essentially rhythmic, and if the tool is slender, or is not firmly supported, a vibratory motion is set up (with chattering sound) and the groove becomes a succession of deep scars. When the grooving tool is a hard boulder held in a slow-moving body of ice, and the thing grooved is a brittle rock, the remaining condition for rhythmic action is probably found in the elasticity of ice and rock, which permits the development of strain and stress before each fracture.

The crescentic crack, being vertical, is presumably a result of tensile stress parallel to the rock face. As the glacier moves forward it tends, through friction, to carry the bed-rock along with it. If the friction on some spot is greater than on the surrounding area, the rock just beneath that spot is moved forward in relation to the surrounding rock through a minute but finite space. This relative movement involves compression about the downstream side of the affected rock and tension about its upstream side, the magnitude of the stresses depending on the differential friction, and rupture ensuing when the tensile stress exceeds the strength of the rock. Exceptional friction may be given by the passage in the ice base of some substance which has a high coefficient of friction in relation to the bed-rock; for example, if the glacier base contains a pocket of sand surrounded by clear ice, the coefficient of friction between the sand and the bed-rock will probably be much higher than between the ice and the bed-rock.

The crescentic gouge is less easy to understand, and it is the purpose of this communication to put forward a hypothetic explanation.

Crescentic gouges have been observed in granite and other massive plutonic rocks, in sandstone, and in limestone. My own observations have been made chiefly in the granite district of the High Sierra, where opportunities for the study of glacial sculpture are exceptionally good. In some localities the gouges are abundant, and in most districts where glacial polish and striation are preserved they can be found by a few

minutes' search. Since my attention was specially directed to the question of their origin I have examined several hundred. A locality of exceptional abundance is represented in plate 39.

In length they measure from a few inches to more than 6 feet, measurement being made in a straight line from horn to horn of the crescent. Within the range of my observation chatter-marks are comparatively small, the largest observed being less than a foot in length. Solitary gouges are often seen, but in the majority of cases they occur in sets of from two to six or seven. Ordinarily the members of the same set have about the same size, but in a few cases a progressive increase was observed, the individual most advanced in the direction of ice motion being largest. It seems legitimate to infer from this arrangement in sets that the cause of the gouge, whatever it may be, moved forward with the ice. As already mentioned, the convexity of the crescent is turned forward; but to this rule there are occasional exceptions. Two or three individuals were seen with the concavity turned forward, and a few also with the longer axis in the direction of ice motion (see plate 38, figure 1). The gouges were seen only on the upstream sides of projecting bosses (figure 1). They are not restricted to the bottoms of glacial troughs, but occur also on the walls, and in that case are on the upstream faces of salients.

Figure 1.—*Profile of Part of Glacier Bed.*

The arrow shows the direction of ice movement. Crescentic gouges occur on ascending slopes, from *a* to *b*.

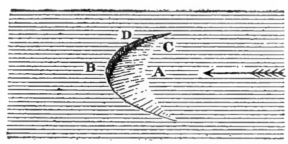


Figure 2.—*Diagrammatic Sketch of Crescentic Gouge.*

The arrow shows the direction of ice movement. Compare figure 3.

Conoid Fracture

The cross-profile of the crescentic gouge (figure 3) exhibits an angular notch bounded by two unequal slopes. The slope from the upstream edge is gentle, that from the downstream edge approximately vertical. This character is exhibited in all parts of the crescent (figure 2). The gentler slope radiates from an axis somewhere within the curve of the crescent and is essentially a portion of a conoid surface. It is one wall of a fracture, or crack, which does not end at the bottom of the gouge, but continues on into the rock to an undetermined distance. The fact that the vertical fracture terminates against the oblique fracture shows that the oblique

was first made. The oblique, or conoid, fracture may therefore be regarded as the primary product of the causative force, and the vertical fracture as secondary; and in seeking a cause of the phenomenon I have given first attention to forces which might be appealed to in explanation of the conoid fracture.

There is another conoid fracture with which geologists are familiar, the fracture often made in obsidian, or other homogeneous brittle rock, by a light blow of the hammer. This is sometimes called the conoid of percussion (see figure 4). Usually it circles completely about its axis, but sometimes it is one-sided. Its relation to the surface struck by the hammer resembles closely the relation of the glacial conoid to the external surface of the bed-rock, and the one fracture may help to explain the other. The conoid of percussion is caused by a blow; that is, by the instantaneous application of pressure to a small area. No way has

FIGURE 3.—*Cross-section of Crescentic Gouge.*

The section represented is from *A* to *B* or *C* to *D* of figure 2.

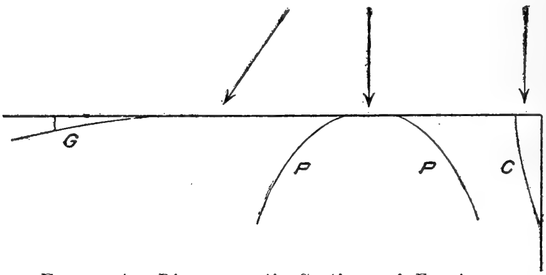


FIGURE 4.—*Diagrammatic Sections of Fractures.*

The horizontal and vertical lines represent the top and side of a mass of rock; *PP*, conoid of percussion, the causative blow being struck in the direction indicated by the arrow; *C*, conchoidal fracture, with arrow showing direction of blow; *G*, conoid and vertical fractures of crescentic gouge, with oblique arrow showing theoretic direction of causative pressure.

occurred to me in which a glacier can make such a fracture by means of a blow, but it seems possible, as I shall presently explain, that a glacier can slowly apply considerable differential pressure to a very restricted area; and there is some reason to believe that suddenness of impact is not essential to the production of conoid fractures. The ordinary conchoidal fracture, which is a near relative of the conoid of percussion, is commonly developed in brittle rock by a blow struck near an edge (figure 4); but it is also produced by simple pressure in the manufacture by Indians of flint and obsidian implements.

In a single instance a conoid fracture in granite was observed to circle completely around its axis (see plate 38), thus simulating still more

closely the conoid of percussion. This feature occurs in a glacial trough where there are many crescentic gouges, but it is not connected by gradation with the ordinary gouges.

Differential Pressure

As a glacier moves forward its under surface is continuously adjusted to the irregular shapes of its bed. The greater inequalities of the channel find expression on the upper surface of the glacier, but the minor inequalities do not affect the upper part of the ice stream. The diagram (figure 5) represents in profile a projection of the bed, of moderate magnitude in relation to the total thickness of the glacier. The adjustment of the glacier to this obstruction affects the flow lines of only the lower strata of ice, leaving unaffected all above some limiting plane, *A B*. Below that limit the lines of motion first ascend and then descend in passing the obstruction. If we think of the flow lines of the diagram as separating layers of ice, then each layer becomes thinner in ascending and gains thickness in descending.*

A large boulder embedded in the glacier close to its base is not reduced in thickness along with the enclosing ice layers, and its resistance to compression develops differential stresses both above and below it. These pressures tend to force it into the overlying ice, and at the same time to force it into the rock bed. As the rock bed effectually opposes the downward motion the boulder is actually forced into the ice body above it (figure 6). A large share of the pressure thus brought to bear on the upper side of the boulder is transmitted by the boulder to the rock bed at their point of contact or approximation, and there is thus a concentration of pressure on a small area of the rock bed. This concentration continues as long as the ice about the boulder is undergoing vertical compression in passing the projection, and ceases when that compression

*The statements of this paragraph are, I think, indisputable; but they are qualitative only. In making a diagram to illustrate them I could not avoid presenting a more definite, and in some sense quantitative, conception of the forms of the flow lines, but of the accuracy of this conception I am by no means confident. Not only is there a third dimension of which account should be taken, but there are complicated interactions connected with differential velocity. In order to pass through the diminished cross-section above the projection, some of the lower layers of ice must take on temporarily a higher velocity, and that acceleration involves both internal resistance and basal friction. The conditions affecting these resistances are notably different on the upstream and downstream sides of the projection, and it is therefore improbable that the curves of the flow lines are symmetric. Moreover, the diagram, by indicating the compression of the lowest layer as greater than that of any other layer, assumes that that layer's temporary increment of velocity is greatest; and this again assumes that the temporary increment of basal friction is not greater than the temporary increment to shearing stress of the ice in planes parallel to the rock surface—a matter as to which I have no information.

ceases. It begins somewhere on the upstream slope of the projection and ceases at its crest. Thus the conditions for localization of pressure by this method have the same distribution in relation to prominences of the rock bed as that observed for the crescentic gouges.

If the ice beneath the boulder is clear of débris, it is probable that a large differential pressure can not be developed without causing the ice to flow away and bringing the boulder into contact with the rock bed. The result to the rock bed of such contact would be a deep scratch or groove, and grooves are not the normal associates of crescentic gouges. It seems necessary, therefore, to suppose that when crescentic gouges were made the direct contact of the boulder was in some way prevented—and the means of prevention is not far to seek. If only the sand and other fine detritus normally abundant in the base of a glacier be assumed to saturate the ice beneath the boulder, a cushion is provided quite compe-

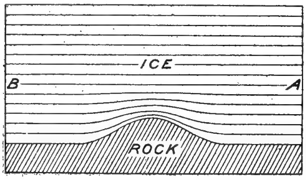


FIGURE 5.—*Longitudinal Section of lower Part of a Glacier.*

The section is supposed to be at a point where it passes a projection of the rock bed, and illustrates the deflection of lines of flow and the temporary compression of the lowest layers of ice.

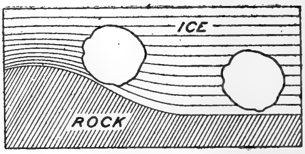


FIGURE 6.—*Longitudinal Section of lower Part of a Glacier.*

The section is on the upstream side of a projection of the rock bed and illustrates the changing relations of an embedded boulder to the system of flow lines. The ice motion is from right to left.

tent to prevent actual contact of boulder and rock bed and at the same time transmit the pressure of the boulder to a small area of the bed.

A complete discussion of this hypothesis would include a mathematical analysis of the mechanics of the conoid fracture. Only the elastician is competent to make such an analysis, and I have not attempted it. Nevertheless, as I have not been able to ignore altogether that aspect of the subject, I shall venture a few lay suggestions.

As the conoid of percussion is symmetric about an axis normal to the surface receiving the blow, and as the conoid of the crescentic gouge is asymmetric, it may be inferred that the direction of the force producing the latter is oblique to the rock surface. In a general way all pressures of the ice upon glaciated bed-rock must be oblique; otherwise there would be no forward motion; but the particular pressure to which appeal has been made in connection with the crescentic gouge is the result of a compression of the ice in the direction normal to the rock face, and should be

regarded, I think, as itself normal. If this view is correct, some other cause must be sought for a special stress component parallel to the rock face.

I think such a cause exists in differential friction. The friction per unit area of the glacier on its rock bed at any point is the measure of the force there applied by the glacier in a direction parallel to the local rock surface. It varies with the material of the two bodies in contact and is directly proportional to the force, normal to the contact surface, by which they are pressed together. Therefore during the period in which the hypothetic boulder communicates an excess of pressure to a small area of the rock bed, the same area experiences a proportionate excess of sliding friction, and is consequently subject to a proportionate excess of force in a direction lying in the plane of contact. The composition of this force with the differential force normal to the plane of contact gives a resultant parallel to the general system of oblique stresses in the surrounding ice. This reasoning appears to warrant the statement that the differential pressure occasioned by the approach of the boulder to the prominence of the rock bed is oblique to the local rock surface and is directed forward.

Deformation and Rupture

To obtain an idea of the nature of the deformation resulting from the differential pressure just mentioned I have tried a few simple experi-

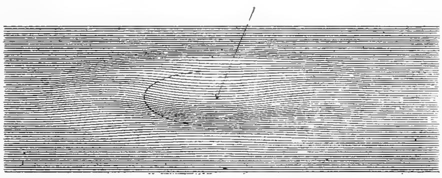


Figure 7.—*Ideal oblique View of originally plane Rock Surface.*

Showing, with vertical exaggeration, its theoretic deformation under the external stress causing a crescentic gouge. The arrow shows the direction of the stress. The direction of ice motion is from right to left. The position of the conoid fracture is indicated by a broken line. Compare figure 8. The lines of the drawing are parallel equidistant profiles of the deformed surface.

ments. If a liquid jelly be allowed to cool in a large bowl it assumes the condition of an elastic solid with a level and smooth upper surface. Pressed by the ball of the finger its surface is deformed, the hollow under the finger being surrounded by a low circling ridge, the slope of which is relatively steep toward the finger but very gentle in the opposite direction. If the pressure of the finger be made oblique the ridge becomes steeper and higher on one side of the hollow, and is correspondingly re-

duced or even abolished on the opposite side. The hollow under the finger is a direct result of the pressure and the curving ridge is an indirect result, the intermediate factors being a complex system of internal strains and stresses.

I conceive that an analogous condition obtains in the rock bed as a result of the oblique pressure under the hypothetic boulder; that there is a central depression of the surface (figure 7); that this is margined on one side by a curved elevation; and that there are internal strains and stresses; but the strains are comparatively small and the slopes of deformation are very gentle, because in rock the strain limit is quickly reached and rupture ensues. The hypothesis assumes that rupture in this case is initiated in the surface of the rock, along the inner slope of the curving ridge (figure 7), and is propagated obliquely downward, forming the conoid fracture (figure 8) of the crescentic gouge.

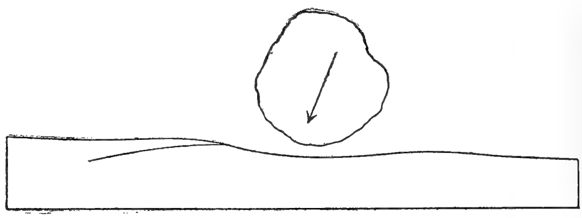


FIGURE 8.—*Theoretic Deformation of Rock beneath a Glacier.*

This ideal section illustrates the theoretic deformation of rock beneath a glacier by differential pressure in connection with an embedded boulder. The arrow indicates the direction of the pressure. The direction of ice motion is from right to left. The conoid fracture of the crescentic gouge is shown at left of the boulder. Compare figure 7.

In the absence of a rigorous analysis of the stresses associated with the deformation, the correlation of the conoid fracture with the curved ridge is an assumption only; but having made that assumption it seems possible to base on it certain inferences tending to throw light on other elements of the gouge. In the production of the deformation the rock compressed vertically under the boulder experienced horizontal dilatation whereby the ridge was pushed up, and the ridge itself experienced horizontal compression. The region of the fracture was thus subjected to horizontal compression just before the rupture, and as soon as the fracture had been formed the wedge of rock above it was relieved of horizontal compression and recovered its original horizontal extent. The wedge had also been bent, its upper surface constituting the crest of the ridge, and when it was detached beneath it tended to recover also its original unbent form by lifting its edge. This change was resisted by the pressure of the overlying ice, with the result that the wedge became affected

by the stresses of a bent beam, compressive below and tensile above. To the tensile stress along the upper part of the wedge I ascribe the vertical fracture which completed the gouge. It is possible that more than one vertical fracture ordinarily occurred, dividing the wedge into several parts.

The position of the vertical fracture, as thus explained, is conditioned (in part) by the distance to which the conoid crack penetrates the rock. Toward the horns of the crescent, where the conoid crack vanishes, the crack probably penetrates less deeply, and the vertical fracture there traverses a thinner part of the wedge; hence the curve given by the intersection of the vertical fracture with the surface is not concentric with the corresponding curve for the conoid fracture, but meets it. Some of these relations are diagrammatically shown in figure 2.

It is worthy of note that the two fractures, referred respectively to shearing and tensile stresses, differ notably in the textures of their sur-

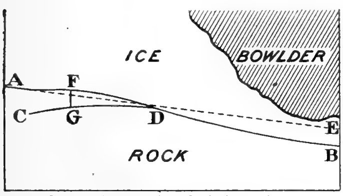


FIGURE 9.—*Theoretic Origin of Fractures producing the Crescentic Gouge.*

This ideal section illustrates the theory of origin of fractures producing the crescentic gouge. *AE,* original (longitudinal) profile of rock bed; *AFDB,* deformed profile of rock bed (with exaggeration of curvature); *DGC,* conoid fracture; *FG,* vertical fracture.

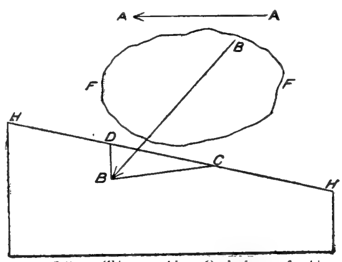


FIGURE 10.—*Theoretic Origin of the oblique and vertical Fractures of the Crescentic Gouge.*

This diagram illustrates the alternative hypothesis for the origin of the oblique and vertical fractures of the crescentic gouge.

faces. The conoid fracture, as seen in figure 1 of plate 37, gives a rather smooth surface, and that produced by the vertical fracture is comparatively ragged. The vertical fracture also departs from regularity more widely than the conoid. In the figure just mentioned the outlines of two of the vertical fractures more nearly resemble right angles than circular arcs.

Since the writing of this paper it has been examined by several friends well qualified to discuss its theoretic part, and as a result of various suggestions and criticisms a number of passages were modified. One of the most important suggestions—but one which I was unable to accept—included the following alternative hypothesis for the origin of the two fractures delimiting the crescentic gouge. I quote: "We will suppose

the glacier is moving in the direction indicated by the arrow *AA;* that the rock floor is indicated by *HH;* that the boulder *FF* is either in contact with or near the rock floor. Under these conditions the direction of the greatest stress would be indicated by the arrow *BB,* being the resultant of the weight of the glacier and the pressure behind the moving mass. Under these conditions there are powerful shearing stresses in the directions *BC* and *BD*. These stresses are greater adjacent to the boulder because it is a rigid body and is able to transmit forward close to the rock floor the pressure of the ice about it. At the place where there is the most rapid change in the amount of compression rupture takes place. Whether the rupture occurs in both the horizontal and vertical directions will depend upon circumstances, which will largely depend upon the shape of the rock surface and the position of the boulder and its shape. When the vertical rupture takes place alone you have the crescentic cracks, when horizontal rupture takes place, followed instantaneously by the vertical rupture, you have the crescentic gouges."

Rhythm

A full development of the hypothesis would include also a discussion of the occurrence of the gouges in series, and this likewise requires the expert knowledge of the elastician. If I again venture a suggestion it is largely in the hope of exciting his interest. There can be little question that each series of gouges represents a mechanical rhythm of some sort. In a large group of mechanical rhythms, including many in which friction plays a part, a force uniformly applied accumulates strain and stress, which are relieved in some catastrophic manner whenever they reach a certain limit. In the present case the conoid rupture is a catastrophic event relieving some of the internal stresses of the bed-rock. The jar, or miniature earthquake, occasioned by it and radiating from the point of rupture may be supposed to overcome frictional resistance between glacier and rock and cause a sudden slipping along their contact surface, thus relieving the frictional strains and stresses for some distance in all directions. The boulder instantaneously moves forward to a new position with reference to the rock bed, and the gradual renewal of deformation and internal strains is begun. This line of inference leads to the difficult question whether the sudden forward movement covers only the fraction of an inch, or whether it may be of the order of magnitude of the interval between gouges—from a few inches to several feet. If it is very small, then the determination of the gouge interval remains as one of the obscure factors of the hypothesis. In a general way the gouge interval is

related to the gouge length, being greater when the length is greater, but there is no fixed ratio between the two. No measurements were made in the field, but photographs show a range in the ratio from about 1:3 to about 2:1.

The discussion of the gouge rhythm also suggests the possibility that the ordinary movement of the glacier on its bed may be rhythmic. It is certainly conceivable that internal strains and stresses of the rock and ice up to the limit given by static friction may be locally engendered during periods of adhesion and then relieved by momentary slipping, with sliding friction only.

Resistance of Ice to Flowage

The crescentic gouge is a large disruptive scar on the face of a compact jointless rock. Any hypothesis to account for it must provide great force. The particular hypothesis here given, instead of appealing to the ferential stress developed by the resistance of the ice to the forcing of a boulder into it. It can not be true unless the ice has great power of resistance to flowage; and, conversely, if it is true, the ice has greater power of resistance than some students have been disposed to admit. It is generally understood that cold ice is more rigid than ice at the melting temperature, but the hypothesis is not concerned with cold ice. Doubtless crescentic gouges are made under cold ice, but the gouges preserved for our observation were not so made. Beneath the forward part of a glacier the basal temperature is the temperature of melting (as conditioned by the pressure); and as a great glacier wanes, every portion of the bed is in turn subject to the action of its forward part. The finishing touches, therefore, the surface markings and the small details of sculpture, can not be ascribed to ice of the low temperatures theoretically obtaining far back under the névé. So the crescentic gouges, as explained, testify to the resisting power of ice at the most favorable temperature for flowage.

Whether we regard ice as a plastic substance, or whether we accept, as I do, the view of Chamberlin, that it is made up of rigid crystalline grains and flows chiefly by interstitial melting and regelation, we must recognize a relation between velocity and resistance to flow. The more rapid the flow the stronger the resistance. Therefore the crescentic gouges, if they have been properly explained, may testify also to relative rapidity of glacier movement.

Nomenclature

The word "gouge" connotes a process of formation analogous to the work of a chisel. It is therefore inappropriate as the name of the dis-

ruptive scar discussed in this paper. The incongruity is heightened by the fact that it might with propriety have been applied to another disruptive scar, the chatter-mark, which also affects glaciated surfaces and is also usually crescentic. In view of this infelicity of nomenclature, I have seriously considered the use of "lunoid furrow," a name given by Packard* to a feature probably, but not surely, identical with Chamberlin's "crescentic gouge." Packard's description, supplemented by a description by Hitchcock,† is so indefinite that Chamberlin cautiously refrained from correlation; but the only definite obstacle to correlation is a cross-profile by Hitchcock in which the relation of steeper and gentler slopes is reversed. If the case were one in which priority had weight, I should make the argument for correlation and use Packard's name; but the instance clearly falls outside the field of priority, and it unfortunately happens that the connotation of Packard's name renders it quite as inappropriate as Chamberlin's. Not only is the feature not a furrow, in the sense of having been plowed, but there is another feature of glacial sculpture, that which in this paper is called a groove, to which the name furrow might be applied with much propriety. The third alternative, to introduce a new name, I have avoided for various reasons. A really apt name does not occur to me, and it is possible that foreign studies of the feature, of which I have no knowledge, have provided an acceptable name. So I have followed the nomenclature of the first paper known to me which clearly distinguishes the principal types of disruptive scars of glacial origin.

*American Naturalist, vol. 1, p. 265.
†Geology of New Hampshire, vol. 3, pt. 3, p. 182.

FIGURE 1.—TYPE FORMS

FIGURE 2.—GOUGES ON UPSTREAM SIDE OF PROMINENCE

CRESCENTIC GOUGES

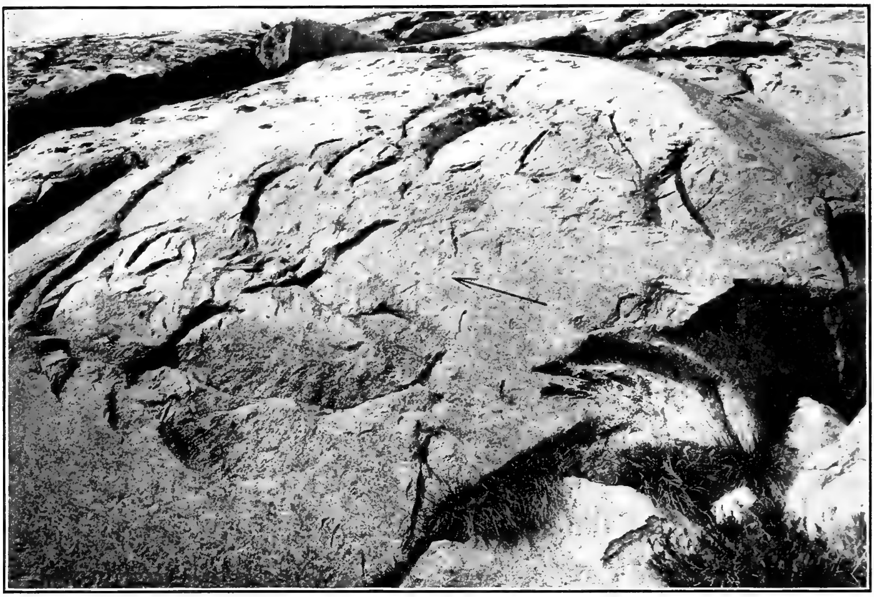


FIGURE 1.—OVERLAPPING AND IRREGULAR CRESCENTIC GOUGES

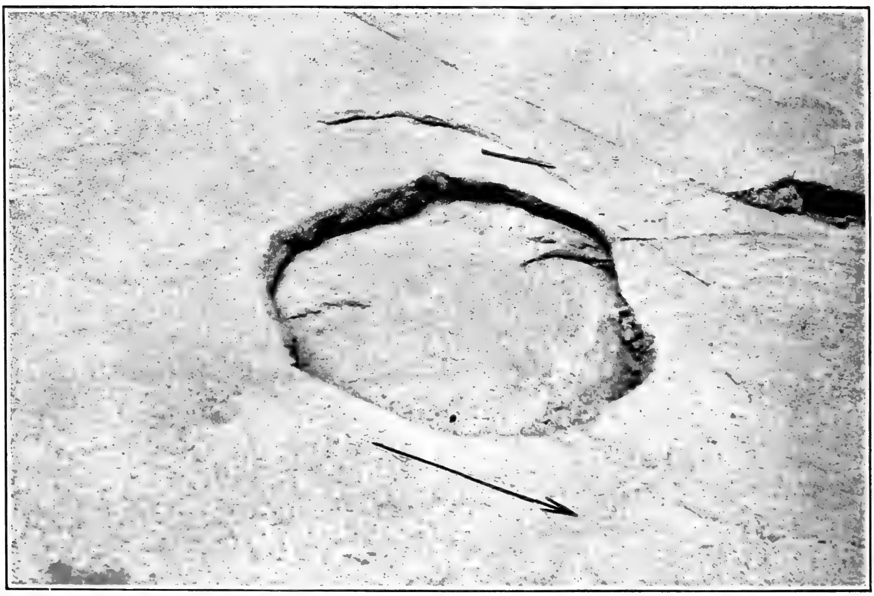
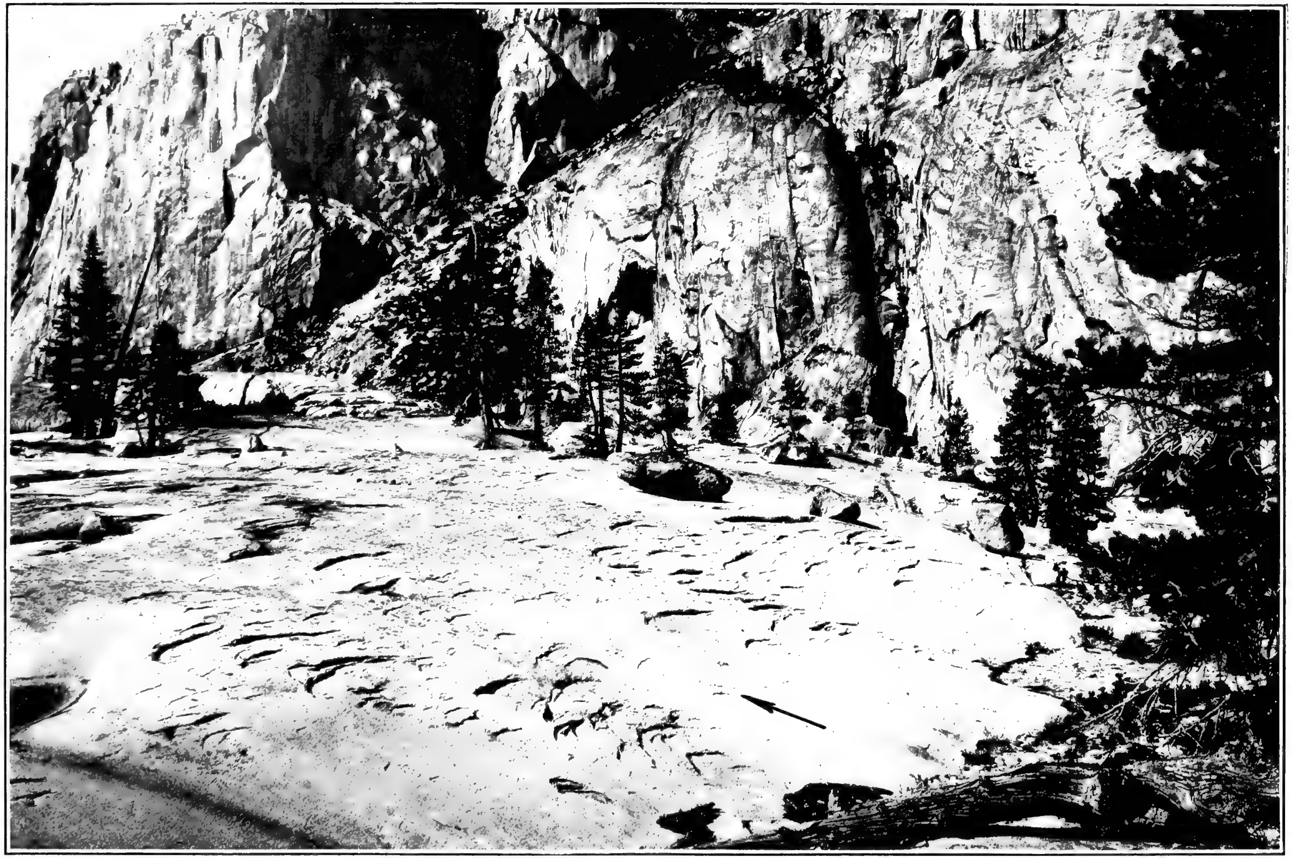


FIGURE 2.—ANNULAR SCAR

DISRUPTIVE SCARS ON GRANITE



CRESCENTIC GOUGES IN TUOLUMNE CANYON

Explanation of Plates

Plate 37.—*Crescentic Gouges*

Figure 1.—Type forms.

The direction of ice motion is indicated by the arrow. The arrow also indicates scale, being one foot long. The nearest gouge is solitary; most of the others are grouped in sets. The blade of the knife is inserted in the conoid crack. The rock face pictured inclines toward the observer at about 45 degrees. The material is granite. The locality is near the base of mount Huxley, Sierra Nevada, and is in the upper basin of Evolution creek, a tributary of San Joaquin river. In the upper part of the field the gouges are obscured by lichens.

Figure 2.—Gouges on upstream side of a prominence.

The arrow, approximately one foot long, indicates the direction of ice motion. Postglacial disintegration has removed the glacial striæ and polish and rounded the edges of the gouges. The rock is granite; the locality is the North fork of Kings river, Sierra Nevada.

PLATE 38.—*Disruptive Scars on Granite*

FIGURE 1.—Overlapping and irregular crescentic gouges.

The arrow, one foot long, indicates the direction of ice motion. The rock face curves down toward the foreground. Evolution creek, near base of mount Huxley, Sierra Nevada.

FIGURE 2.—Annular scar.

The crack occasioning this scar extends obliquely down in all directions. The rock face is nearly horizontal. The arrow, one foot long, shows the direction of ice motion. Valley of Evolution creek, above Evolution lake, Sierra Nevada.

PLATE 39.—*Crescentic Gouges in Tuolumne Canyon*

The part of the canyon represented is nearly opposite Wildcat point, Sierra Nevada, and is approximately in latitude 37° 55′, longitude 119° 27′. The canyon floor is here a gigantic stairway; the view shows the tread of one of the stairs. The direction of motion is shown by the arrow. The glacier reached this spot by descending a slope of about 25 degrees, and here began to ascend a slope of 2 to 5 degrees. Another steep descent begins at the extreme left. The gouges are so numerous that their overlapping obscures their arrangement in sets. Some of the cracks of the granite are probably remnants of conoid cracks, the gouges with which they were once associated having been removed by subsequent abrasion.

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MOULIN WORK UNDER GLACIERS*

BY G. K. GILBERT

(*Read before the Cordilleran Section of the Society December 30, 1905*)

CONTENTS

STATEMENT OF THE PROBLEM STUDIED

In glaciated regions I have several times encountered an aberrant and puzzling type of sculpture. Inclined surfaces, so situated that they can not have been subjected to postglacial stream scour, are sometimes carved in a succession of shallow, spoon-shaped hollows, and at the same time are highly polished. They resemble to a certain extent the surfaces sometimes wrought by glaciers on well-jointed rocks, where the hackly character produced by the removal of angular blocks is modified by abrasion; but they are essentially different. Instead of having the salient elements well rounded and the reentrant angular, they have reentrants well rounded and salients more or less angular; and they are further distinguished by the absence of glacial striæ.

An example appears in the foreground of plate 40, representing the canyon of the South fork of the San Joaquin river, in the heart of the glaciated zone of the Sierra Nevada. The peculiarly sculptured spot is high above the river.

ORIGIN OF THE ROCK SCULPTURE

The key to the puzzle was found on a dome of granite standing at the southwest edge of Tuolumne meadow, Sierra Nevada, just north of the Tioga road. The dome is several hundred feet high and in general is

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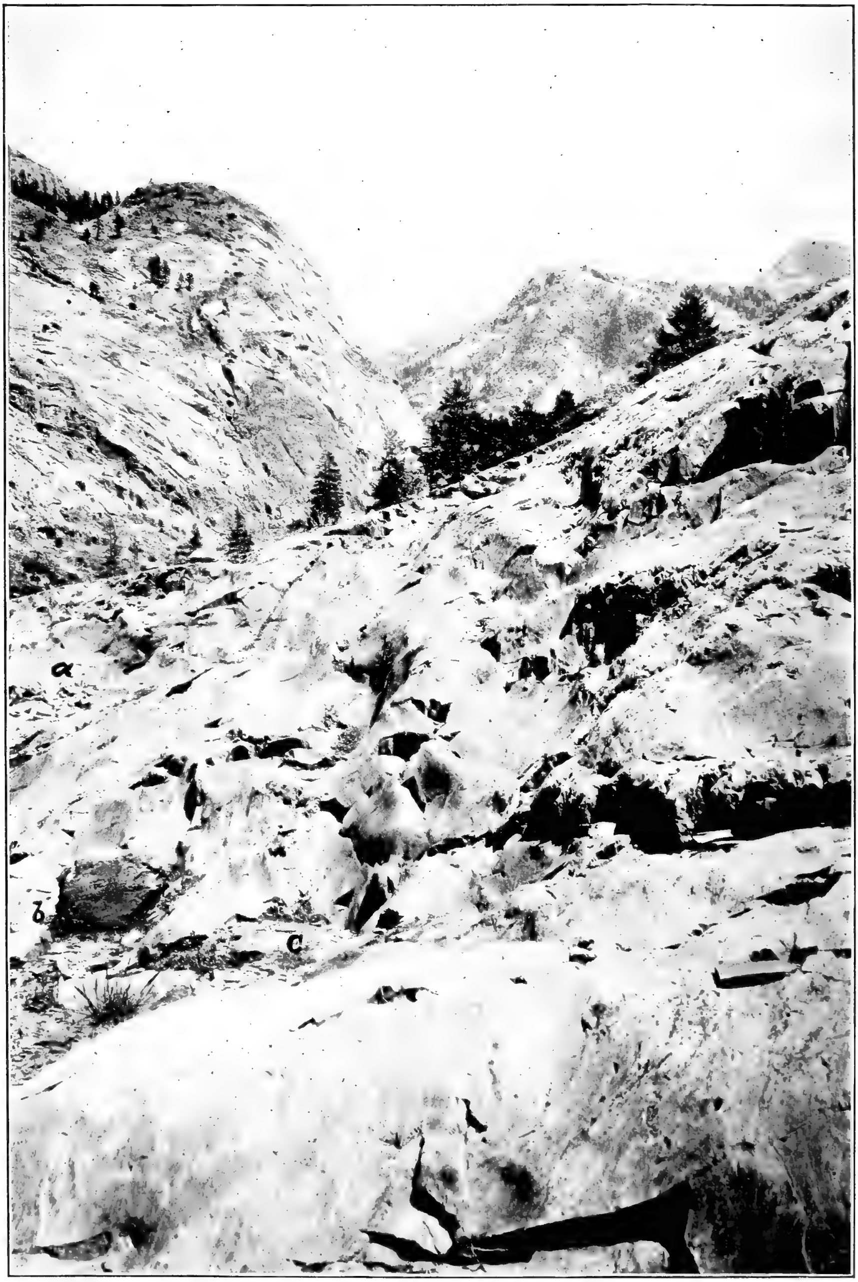
smoothly curved, its form being due partly to exfoliation and partly to erosion by the deep Pleistocene ice-stream of the Tuolumne basin, which passed over it from east to west. On the southern face, where the general slope is about 20 degrees, occurs the peculiar flexuous sculpture, and in close association with it are several potholes. The pothole figured in plate 41 has its mouth about 40 feet above the visible base of the dome, and there are others somewhat higher. They are not to be explained by any conceivable river or creek, and I have no hesitation in ascribing them to moulin work at some stage of the last glaciation of the district. With their aid it is easy to recognize the associated shallow hollows as imperfectly developed potholes.

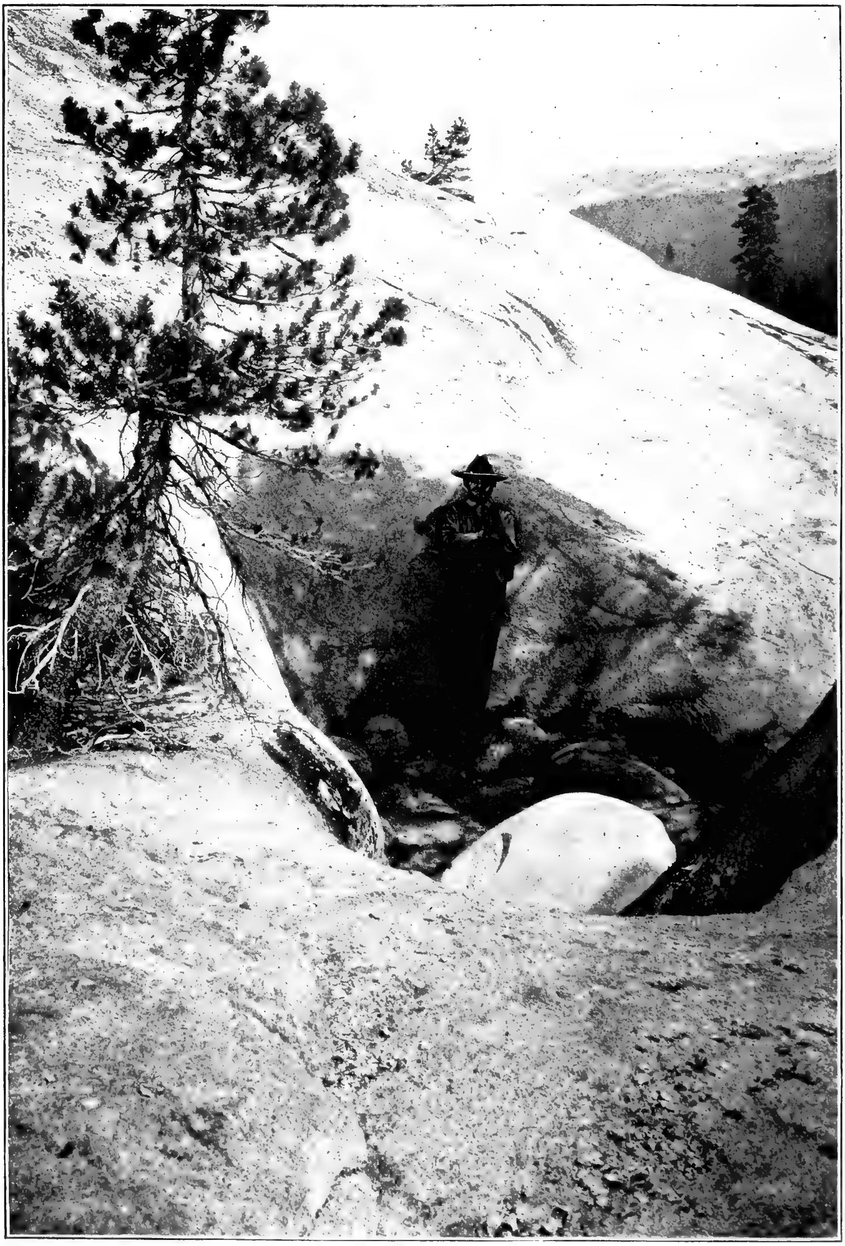
The Moulin, or glacial Mill

A moulin, or glacial mill, is a stream of water plunging from top to base of a glacier through a well of its own maintenance. The water is derived from ablation, has a course on the surface of the glacier before reaching the well, and escapes from the bottom of the well by a channel beneath the glacier. The well originates in a crevasse, the crevasse results from a strain of the glacier, and the strain is related to some local deflection of the ice-stream. Initially the crevasse must extend from top to bottom of the glacier, so as to admit and transmit the water stream. Afterward it is closed below by the welding of its walls, except where the falling water maintains an opening. The opening thus acquires a cylindric form, and is completely adjusted to the water, permitting it to plunge downward, with little or no deflection, and strike the rock bed with great force. As the glacier moves forward the moulin is carried with it. After a time a new crevasse is opened at the same turn of the ice current; it intercepts the stream of water and a new moulin is made; and the earlier well, being deprived of its water, and therefore unable to resist the encroachment of the quasi-plastic ice, becomes sealed. The new moulin and others after it repeat the course and the history of the first. At the base of the ice the plunging water finds boulders and sand, and with these, its familiar tools, attacks the rock bed. Some detail of the configuration of the bed, the presence of a large boulder held by the ice, or some other local condition, permanent or temporary, guides the water in such way as to determine scour at a particular spot, and a shallow hollow is made. As successive moulins pass the spot the hollow itself serves as a condition to determine further scour at the same spot. At the same time the hollow serves to prevent scour in its immediate vicinity, but when the moulin has moved beyond its influence another hollow may be initiated. As



MOULIN WORK

San Joaquin Canyon, Sierra Nevada



MOULIN WORK

Near Tuolumne Meadows, Sierra Nevada

MOULIN WORK

Mokelumne Canyon, Sierra Nevada

moulin follows moulin and summer follows summer, the hollows are deepened and assume the character of potholes. As I understand it, a pothole is developed only where rock fragments are carried round and round by whirling water. Mere impact of the plunging water is not sufficient if there is no inclosure or obstruction to determine a whirl. After a hollow has been made and the condition for a whirl thus permanently localized, the whirl may be maintained by violent motion of the water anywhere about its rim; so that the deepening of the pothole progresses whenever a moulin stream strikes near it. If a moulin stream of pure water strikes the divide between two potholes it may furnish power for the simultaneous drilling of both holes without eroding the partition between them.

If the surface conditions of the glacier are such that successive moulins follow closely the same track, there may be a long row of potholes, and with changing conditions there may result either parallel rows or an irregular distribution. In Turner's classic photograph of the potholes of Mokelumne canyon (plate 42) at least three parallel rows may be seen.

The imperfect potholes of the peculiar flexuous surfaces may sometimes be imperfect in the sense that they are incipient, but the greater number are probably surviving parts of potholes that were once complete. Just as there are one-sided lake valleys and one-sided water channels where the complementary sides were of Pleistocene ice, so, I think, the complementary parts of these imperfect potholes were of ice, more or less fortified by included rock débris.*

After the water of the moulin has reached the rock bed it must escape along some course beneath the ice. In flowing away it may accomplish erosion of the ordinary type, and the sculpture resulting from stream erosion may therefore be associated with moulin sculpture.

*Since the writing of this paragraph I have learned that the same explanation was published by Von Post forty years ago. Brögger and Reusch cite him as follows: "The parts now wanting in what now appear unfinished kettles he believes were composed of ice; so that in this case also water might have whirled stones and rubbish round the inside of a kettle consisting partly of rock and partly of ice." Quart. Jour. Geol. Soc. London, vol. xxx, p. 765, 1874.

Explanation of Plates

Plate 40.—*Moulin Work, San Joaquin Canyon, Sierra Nevada*

The view looks up the canyon of the South fork of San Joaquin river toward the mouth of Evolution creek. The rock of the foreground is slate, with vertical structure. The sculpture of a tract in the foreground, especially the spoon-shaped hollows with débris, *a, b, c,* is ascribed to moulin action. Just beyond this tract the profile of the canyon wall, outlined against trees, is of the normal glacial type.

Plate 41.—*Moulin Work, near Tuolumne Meadows, Sierra Nevada*

The view looks eastward. The general direction of Pleistocene ice movement was from distance to foreground. The pothole in the foreground is nearly filled by débris, among which are highly polished boulders. The pine at the left is rooted in another pothole, and the more distant pine probably occupies a third. At various points beyond the nearer pothole the general slope is interrupted by imperfect potholes. The granite is without joints and without schistosity. The lines, suggestive of structure, which descend the slope are surface stains.

Plate 42.—*Moulin Work, Mokelumne Canyon, Sierra Nevada*

The locality is under the north wall of the canyon of the North fork of Mokelumne river, 5 miles northwest of Bloods (north boundary of Big Trees quadrangle of U. S. Geological Survey Atlas). The view looks upstream.

The direction of ice movement may be assumed as parallel to the canyon wall. It will be observed that a considerable number of the potholes are arranged in rows parallel to the canyon wall. There is a row of four holes between *A* and *B*, one of seven holes between *C* and *D*, and one of four holes between *E* and *F*. The last mentioned row possibly begins at *G* and includes eight holes between *G* and *F*.

The photograph is by H. W. Turner, who described the locality in the American Journal of Science in 1892 (third series, volume 44, pages 453-454). He states that the potholes are about 250 in number, that they are from 6 inches to 6 feet apart, that few or none coalesce, and that the lowest of them are 20 or 30 feet above the river.

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GRAVITATIONAL ASSEMBLAGE IN GRANITE*

BY G. K. GILBERT

(Read before the Cordilleran Section of the Society December 30, 1905)

CONTENTS

Introduction

In the higher parts of the Sierra Nevada the dominant rock is granite. By reason of Pleistocene glaciation the exposures are exceptionally fine. Over broad areas glacial erosion has removed the products of decay, laying bare the unaltered rock, and large portions of these areas are free from glacial débris. On most of the drift-free surfaces postglacial decay has made little progress and vegetation has as yet no foothold. In many places one can walk for miles on firm granite, and tracts of ideally perfect exposure are often many acres in extent. Taking account of the further fact that the summer climate is usually dry, I regard the region as one of the finest in the world for the study of problems associated with large bodies of granite.

My acquaintance with the Sierra granites is superficial and fragmentary. While engaged in physiographic and glacial studies I have traversed them on several lines, and finding my attention attracted by some of their conspicuous features have made a desultory record with notebook and camera. As I am not versed in either the methods or the lore of the petrographer, it has not seemed best that I attempt either to round out my field observations or to supplement them by office study, and this publication is undertaken chiefly for the purpose of directing attention to what I regard as a superb field for the study of the mechanics and physics of large plutonic

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bodies. The publication does not cover all my observations, but selects those in reference to certain assemblages of crystals and inclusions. The word "granite" is used in its broadest sense, including rocks to which the discriminating petrographer would give several different names.

Feldspar

One of the broadly developed granite types of the Sierra is of pale color, being composed chiefly of feldspar and quartz, with moderate amounts of mica and hornblende. It is characterized by very large phenocrysts of feldspar, the crystals ranging in diameter from one inch to four inches. Ordinarily these are scattered through the rock at intervals ranging from two to four or five diameters of the phenocryst, but there are many spots where they are so closely aggregated as to be in actual contact. Such aggregations are usually from a few feet to a few yards in extent. Their boundaries may be definite or indefinite. They are more abundant in regions where the phenocrysts are comparatively large. The one represented in the illustration is composed of crystals from 2½ to 4 inches in greatest diameter. The crystals of an aggregation, although in contact, do not interfere one with another. Their interstices are occupied by smaller crystals, like those of the general mass of granite. These characteristics seem to me to indicate that the crystals were not formed in juxtaposition, but were in some way assembled after completion; and the hypothesis I suggest is that they were assembled by gravity, being either lighter or heavier than the magma from which they had crystallized. Their great size is favorable to the hypothesis that they were propelled through the magma, for the propelling force, differential weight, is proportional to the cube of the diameter, while the resistance of the magma is proportional to the square of the diameter.

Localities at which the phenomena have been observed are the uplands about Tuolumne meadows, and the vicinity of Cooper meadow on the headwaters of Yuba river. The locality of the illustration, plate 43, is one mile and a half east by south of McGee lake, in latitude 37° 53′.8, longitude 119° 24′.3.

Hornblende

Granites of light gray color, but somewhat darker than the last mentioned, exhibited in places a similar assemblage of hornblende. The hornblende crystals range in length from three-eighths to three-fourths of an inch. The largest assemblages seen are 6 or 7 yards wide and their limits are indefinite. In one instance there is a definite limit on one side. The hornblende crystals are not so closely packed as are the feldspar

crystals mentioned above. Here again the hypothesis offered is that of gravitational assemblage. At ordinary temperatures hornblende is 20 per cent denser than quartz and feldspar, the dominant minerals of the rock. If the same ratio obtains at the temperatures at which the magma congealed, the phenocrysts of hornblende might sink through the viscous magma without requiring such advantage of size as the feldspars possessed.

The locality represented in the illustration, plate 43, is on the east base of mount Silliman, in latitude 36° 39′, longitude 118° 41′. Another locality is on the north slope of the dome called Liberty Cap, at the head of Yosemite valley.

Banding

A third phenomenon with which I am disposed, though less confidently, to associate gravity is a banding of granite. About one mile south of Cooper meadow, just to the left of the trail leading to Upper Relief valley (in latitude 38° 13′, longitude 119° 49′.3), there is a body of granite, some scores of feet in thickness and some hundreds of yards in length, which is conspicuously banded throughout. The rock is of rather fine texture and composed of quartz, feldspar, mica, and hornblende. The bands are alternately dark and pale, the color of dark bands being given by the dominance of hornblende and mica, that of the pale bands by the dominance of feldspar and quartz. They range in width from one inch to nearly or quite one foot. Some of the dark bands are darker than others; some of the pale bands are paler than others. The transition from a pale band to a dark may take place in a quarter of an inch or be diffused through an inch. The more abrupt transitions are from a pale band below to a dark band above. Within both dark and pale bands the attitudes of minerals seem to be wholly irregular. There is no parallelism of orientation and nothing about the rock suggests schistosity.

Several instances of unconformity were observed, as though the various bands had been successively deposited and the history of deposition had been interrupted by temporary erosion. Such a plane of unconformity appears in plate 44, opposite the man's wrist. At another locality, the southeast base of Goat mountain, in the Kings River basin (latitude 36° 51′.3, longitude 118° 34′.2), unconformity is associated with a discordance of dip of more than 20 degrees. I did not there see the rock *in situ,* but the banding is fully and characteristically displayed in a large boulder. Figure 1, based on a diagrammatic field sketch, represents a portion of the boulder.

I think that these bands are not only apparently but actually the result of deposition, and that the unconformities have been caused by erosion

and subsequent deposition. When the phenomena of the boulder (which happened to be first observed) stood alone, I entertained as an alternative the hypothesis that the unconformity was occasioned by the fortuitous juxtaposition of parts of a dislocated body of banded rock; but the unconformities of the Cooper Meadow locality do not admit of that explanation. In each example the bands of the body below the plane of unconformity are obliquely transected, while the bands of the body above the unconformity are continuous.

In each unconformity the lowest band of the upper series, that which rests directly on the eroded surface of the lower series, is one of the dark bands. This fact, taken in connection with the fact that the dark bands are more sharply separated from the pale bands below them than from the pale bands above them, suggests the hypothesis that a pair of bands—dark below and pale above—constitute the unit of deposition.

FIGURE 1.—*Banding and Unconformity in Granite.*

As to the general nature of the deposition, two ideas have occurred to me: (1) that the granite is metamorphic and the dark and pale bands were originally aqueous sediment; (2) that the granite is igneous and the bands were deposited from and partly eroded by liquid magma in motion. The first of these is opposed by the absence of schistosity, by the fact that the bands seem to lie in their original positions without distortion, and by the fact that the less siliceous bands, instead of the more siliceous, lie next to the planes of unconformity, thus reversing the normal order for aqueous deposition. The second suggestion, of deposition from a liquid magma, is too little developed for critical consideration. To constitute a useful working hypothesis it should be supplemented by the suggestion of conditions determining deposition and erosion.

If deposition was from a magma, and if the unit of deposition was a double layer, with dominance in its lower part of the heavy minerals, mica and hornblende, and dominance in its upper part of the relatively light minerals, quartz and feldspar, then gravity may have played a rôle in the process of deposition.

Inclusions

Some of the Sierra granites are practically devoid of inclusions. Others show inclusions at all exposures. A body of light gray granite in the Kings River country, occupying a territory of unknown extent but not

less than 20 miles across, was nowhere observed without inclusions. The inclusions are all of one type, being composed of the same minerals as the matrix but with a larger percentage of mica and hornblende. They are somewhat finer grained than the including rock and they contain small phenocrysts of white feldspar. Similar phenocrysts occur in the matrix, but are less conspicuous because the general color of the rock is paler. A further characteristic of the inclusions is their small size. Ordinarily they range from two or three inches to about a foot in greatest diameter, and the largest seen is only three feet across. In a general way they constitute the tenth or twentieth part of the mass (plate 45, figure 1), but there are many belts and limited tracts where they are much more abundant, and in some places they form more than half the rock (plate 45, figure 2). When closely aggregated they do not touch one another, but are always separated by selvages or interstitial fillets of the matrix. In form they range from oval to angular, the angular individuals having rounded corners. Where they are closely assembled they indent one another in such manner as to indicate plasticity. Their boundaries are definite in the sense that there is not a gradual transition from inclusion to matrix, but are not sharply drawn like those of a pebble in a conglomerate. The inclusions do not separate from the matrix in weathering. While the inclusions are all of one type, they differ in size of grain and also to some extent in shade. Where they are closely aggregated, individuals of different shade and texture may be seen side by side. The assemblages may be only a few feet or a few yards across or may be several hundred feet in extent. Often they constitute belts traversing the ordinary granite, and sometimes the belts show evidence of flowage, all inclusions being elongated parallel to the general direction of the belt (plate 46). In extreme cases this elongation is carried so far that the individual inclusions become difficult to trace and the general appearance is that of banding, but there is no development of schistosity.

Somewhat similar inclusions observed a little farther south by Knopf and Thelen* are regarded by them as concretions. A concretionary explanation of the inclusions of the Kings River region would account for their omnipresence, for their uniformly small size, and for the frequent recurrence of the oval outline. It seems to be opposed by the dominance of subangular outlines and by the uniformity in texture of each individual in all its parts. There is no suggestion of concentric structure. While I gave some consideration in the field to the possibility of concretionary origin, the hypothesis more prominently in mind was that of fragmental

*A. Knopf and P. Thelen, Sketch of the geology of Mineral King, California: Univ. Cal. Pubs., Geology, vol. 4, pp. 236-239.

derivation from an older plutonic body. This hypothesis still seems to me the more available, but is held lightly, partly because it does not readily explain the small size of the inclusions and partly because it has been compared with macroscopic data only. Using it as a working hypothesis in the field, I interpreted the subangular forms of the bodies as fracture forms modified by partial solution in the enveloping magma.

Assuming the inclusions to be of fragmental origin, it seems evident that they experienced partial refusion while in the including magma. A plastic condition is implied by their deformation through interference where they are crowded close together, and also by the fact that they yielded to squeezing with the same facility as the surrounding magma. Had they been more rigid than their matrix, they would have been forced into contact before suffering elongation (see plate 46).

Assuming them to be fragmental, it is an open question whether their close aggregations are best explained as features of original distribution or as the result of gravitational assemblage. The first explanation accounts best for the long belts of closely grouped inclusions separating tracts in which they are sparse. The second accords best with the mingling of inclusions of diverse texture and also with the rounding of angles. A mass of angular fragments associated with little more matrix than was required to fill the interstices would have small opportunity for surface modification by solution.

In the vicinity of Cooper meadow, on the upper Yuba river, a very different granite, a pale variety with large feldspar phenocrysts, contains an abundance of small inclusions, and these also are in places closely assembled. In this case the inclusions vary through a much wider petrographic range and their history is more complex.

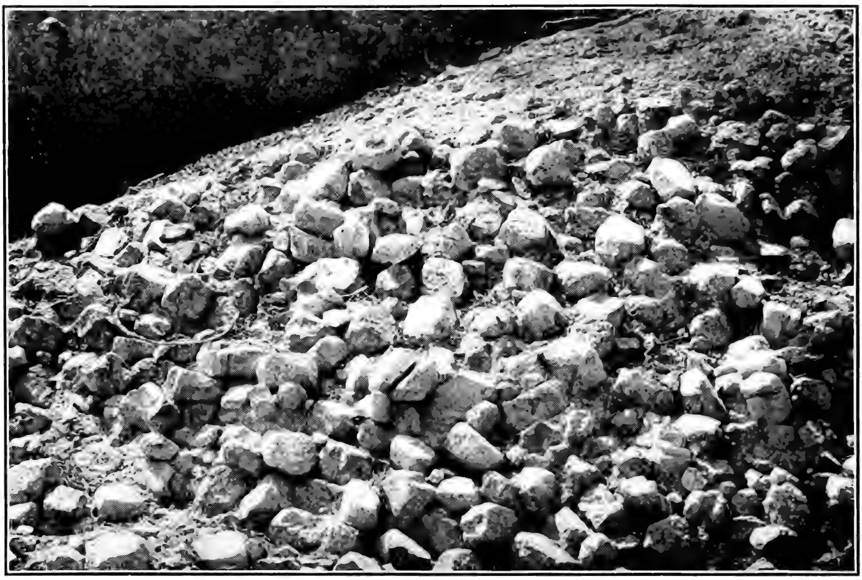
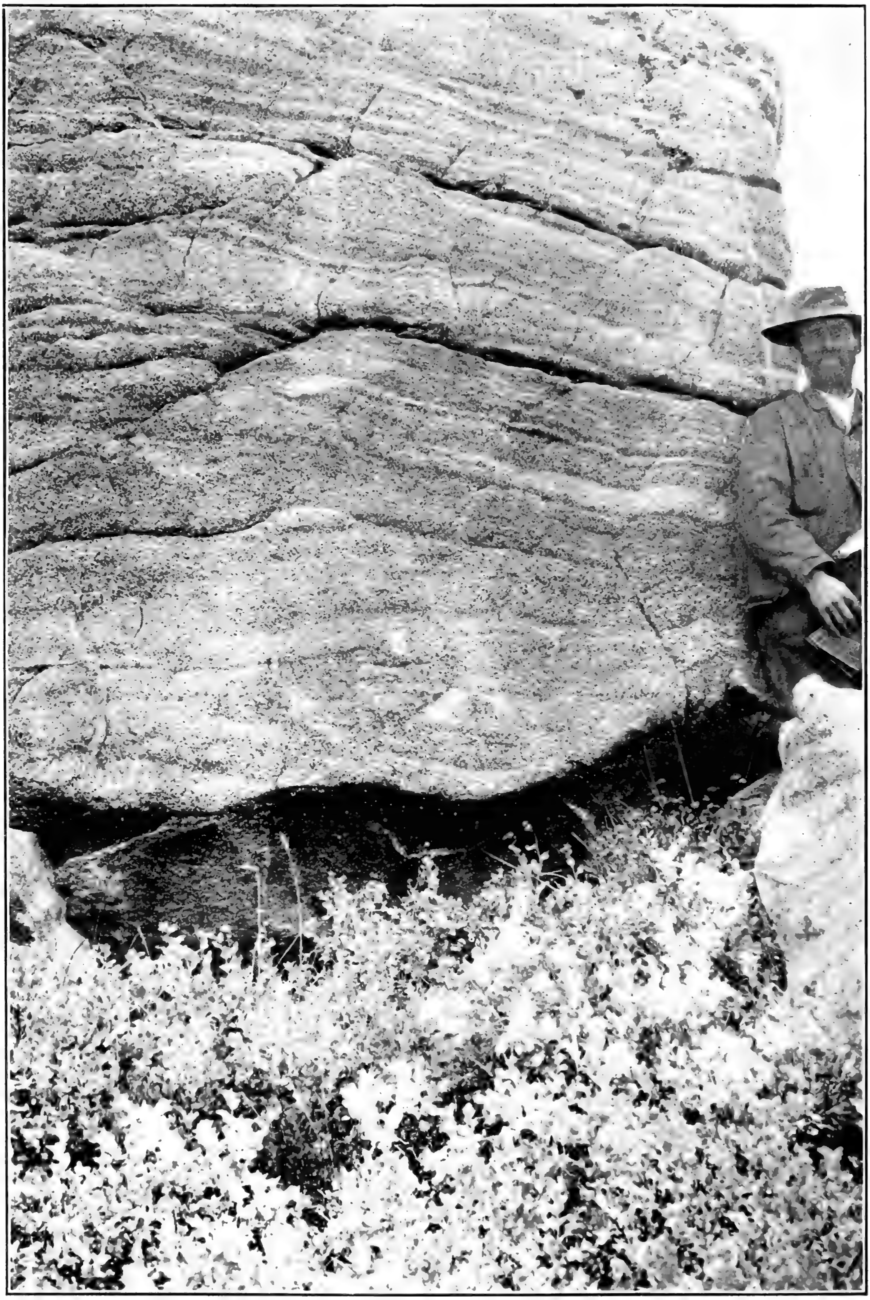


FIGURE 1.—FELDSPAR

FIGURE 2.—HORNBLENDE

ASSEMBLAGES OF PHENOCRYSTS IN GRANITE



BANDED GRANITE

FIGURE 1.—NORMAL DISTRIBUTION

FIGURE 2.—AN ASSEMBLAGE

INCLUSIONS IN GRANITE OF KINGS RIVER REGION

COMPRESSED INCLUSIONS

Explanation of Plates

Plate 43.—*Assemblages of Phenocrysts in Granite*

Figure 1.—Feldspar.

The locality is on the north slope of a granite dome, between Tuolumne meadows and McGee lake, Sierra Nevada. The crystals are *in situ*, being brought into relief by the weathering of the granite. The upper limit of the assemblage appears in the view, and above it some of the ordinary granite. The view covers a width of three feet.

Figure 2.—Hornblende.

The locality is at the base of mount Silliman, near a branch of Sugarloaf creek, Sierra Nevada. The view shows the upper part of an assemblage. The granite immediately above is nearly normal, but has a slight excess of hornblende. The white patches at right are of aplite. The hammer handle, giving scale, is 15 inches long.

Plate 44.—*Banded Granite*

The locality is one mile south of Cooper meadow, in the upper basin of the South fork of Stanislaus river, Sierra Nevada, near the middle of the Dardanelles quadrangle of the U. S. Geological Survey Atlas. An unconformity is shown to the left of the man's wrist.

PLATE 45.—*Inclusions in Granite of Kings River Region*

FIGURE 1.—Normal distribution.

The locality is on the northeastern slope of mount Silliman, Sierra Nevada, near its base. The inclusions are distinguished from various patches of surface discoloration by their compact forms and simple outlines. The largest inclusion has a diameter of about one foot.

FIGURE 2.—An assemblage.

Face of a boulder lying near the main trail through Kings canyon, Sierra Nevada. Scale is given by a steel tape, three feet long, near the middle of the view.

PLATE 46.—*Compressed Inclusions*

The locality is on the middle fork of Dougherty creek, Sierra Nevada, in the northeast part of the Tehipite quadrangle, U. S. Geological Survey, and approximately in latitude 36° 54′, longitude 118° 36½′. An assemblage of inclusions having the form of a belt is shown in perspective, some of the normal granite appearing on each side. All the inclusions are elongated in the direction of the belt and compressed laterally. The inclusions show differences in shade and texture.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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THE OKANAGAN COMPOSITE BATHOLITH OF THE CASCADE MOUNTAIN SYSTEM*

BY REGINALD A. DALY

(Read before the Society December 30, 1905)

CONTENTS

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Introduction

From end to end the Coastal division of the North American Cordillera, including the Sierra Nevada, Cascade Mountain system, the British Columbia Coast range, the Alaska, Saint Elias, and other ranges, comprising an area more than six times that of the Alps of Europe, is now proved to inclose granitic masses of great size and importance. Most of them are of post-Archean dates, and it is even probable that the greater number belong to post-Paleozoic epochs.* Many of the Californian stocks and batholiths and a few batholithic masses in the state of Washington have been carefully studied. Much work has been done, too, in the yet more extensive granitic fields of Alaska and British Columbia; but this work has generally been incidental to long reconnaissance surveys, wherein detailed investigations could not be profitably undertaken. In the Sierra Nevada the post-Paleozoic granitic rocks—granodiorites—are largely, if not entirely, of Mesozoic age. In Alaska and northern British Columbia the great "Coast Range batholith" is reported to be of very similar composition, but details as to the development of this colossal body are still largely lacking. Midway in this vast coastal mountain division lies the International boundary, at the 49th parallel of latitude.

On that line the writer has constructed a geological section which throws light on the nature and origin of the granites and tends to bring out the connection between the widely distant northern and southern regions, where Cordilleran study is now being so energetically pursued in government surveys. The results of the work on the 49th parallel corroborate some of the leading conclusions of Dawson, Russell, Willis, G. O. Smith, Calkins, Mendenhall, and others who have carried on researches in the adjacent parts of Washington and British Columbia. The solution of the problems of these granites, as of all granites, primarily demands the patient, careful accumulation of field facts. The big scale of the phenomena, their unusually perfect exposure among these splendid mountains, and the mere fact that much of the area described has never been

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*Cf. A. C. Lawson, Journal of Geology, Chicago, vol. i, 1893, p. 579.

touched with a geological hammer are other reasons for placing on record the results of the Boundary survey.

Geographical Subdivision of the Cascade Mountain System

In 1901 Messrs G. O. Smith and F. C. Calkins, of the United States Geological Survey, made a reconnaissance survey of the 10-minute strip crossing the Cascade range immediately south of the 49th parallel. Their report gives a succinct account of this part of the mountain system which may well serve to locate the region here to be treated. Two paragraphs may be quoted from the report:

> In northern Washington, where the Cascade mountains are so prominently developed, the range is apparently a complex one and should be subdivided. This was recognized by Gibbs, who described the range as forking and the main portion or "true Cascades" crossing the Skagit where that river turns west, while the "eastern Cascades" lie to the east. Bauerman, geologist to the British commission, recognized three divisions, and as his subdivision is evidently based upon the general features of the relief it will be adopted here. To the eastern portion of the Cascades, extending from mount Chopaka to the valley of Pasayten river, the name of Okanagan mountains is given, following Bauerman. To the middle portion, including the main divide between the Pasayten, which belongs to the Columbia drainage, and the Skagit, which flows into Puget sound, Bauerman gave the name Hozomeen range, taken from the high peak near the boundary. For the western division the name Skagit mountains is proposed, from the river which drains a large portion of this mountain mass, and also cuts across its southern continuation. It will be noted that the north-south valleys of the Pasayten and the Skagit form the division lines between these three subranges, which farther south coalesce somewhat so as to make subdivision less necessary.
>
> The Okanagan mountains form the divide between the streams flowing north into the Similkameen and thence into the Okanagan and those flowing south into the Methow drainage. In detail this divide is exceedingly irregular, but the range has a general northeast-southwest trend, joining the main divide of the Cascades in the vicinity of Barron. The highest peaks, such as Chopaka, Cathedral, Remmel, and Bighorn, have a nearly uniform elevation of 8,000 to 8,500 feet and commonly are extremely rugged. Over the larger portion of this area the heights are above 7,000 feet, and below this are the deeply cut valleys.*

The sketch map, figure 1, shows the position of the boundary line in the Cordillera and of the section described in the present paper.

Area covered by the Boundary Commission Survey

Since the year 1901 the United States surveyors attached to the International Boundary Commission have prepared an excellent contour map

*Bulletin no. 235, U. S. Geological Survey, 1904, p. 14.

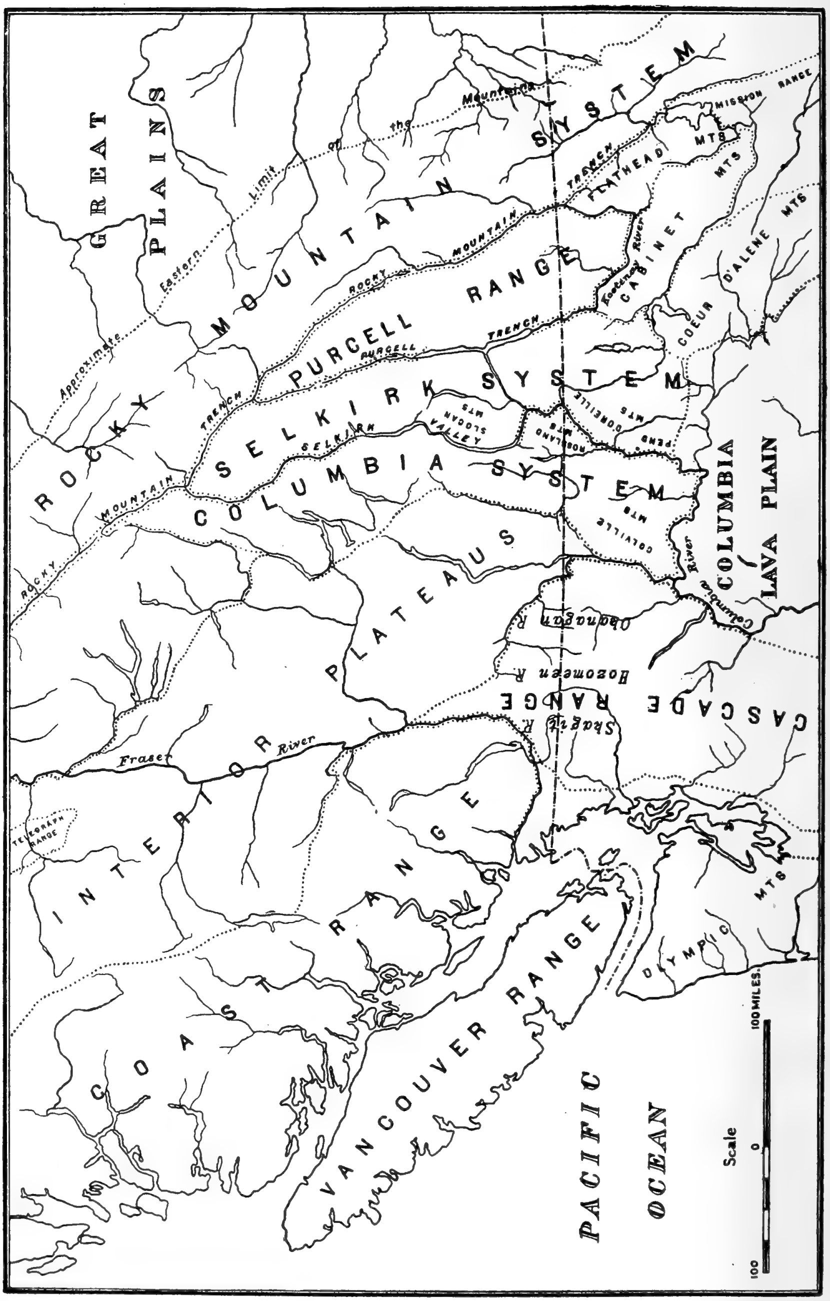

FIGURE 1.—*Map showing Relation of Cascade Range to other Members of the Cordillera.*

of a belt crossing the Cascades between the Similkameen and Skagit rivers and exactly bisected by the international line. To the officials at Washington the writer is indebted for the use of this map in manuscript. The belt averages 5 miles in width. The geology of the belt has been plotted on the map, and the section has been continued eastward by the use of a contour map of a similar 5-mile belt crossing the Interior plateaus east of Similkameen river; in the latter map the international line forms the southern limit. The total area of the belt which is of present interest is about 400 square miles. The part lying within the Hozomeen range—that is, west of Pasayten river—covers greatly deformed strata of Cretaceous age. The remainder, or three-fourths, of the belt is underlaid by the vast assemblage of plutonic intrusive rocks which had been briefly described by Smith and Calkins.

This strip of rugged mountains forms part of a huge batholithic area that will be adequately mapped only after many more seasons of arduous field-work. The geological findings within such a belt as now to be described would be much increased in value if they could be systematically compared with field studies throughout the whole batholithic province. For many reasons such a complete survey is now impracticable. The present paper is thus a sort of report of progress on the geology of these crystalline rocks of the northern Cascades. Nevertheless discoveries of prime importance to the geology of the entire range have been made within even the limited area of the 5-mile belt. Certain of the broader conclusions there deduced may, it is believed, be relied on, and will not need serious emendation as the exploration of the mountains continues. In the following pages there is offered another class of considerations which are theoretical and need the facts of the field, especially of the whole Cascade field, for their full discussion. In these matters particularly, a 5-mile belt can not speak for the whole Okanagan range, except as geological experience in that belt accords with verified geological experience the world over.

General Description of the batholithic Area and Location and relative Size of its Units

From the eastern slope of the wide valley occupied by Osoyoos lake to the Pasayten river, an air-line distance of just 60 miles along the boundary, the mountains are composed of almost continuous plutonic igneous rocks. This immense mass is markedly heterogeneous. To simplify the following discussion it will be well to review the general geographical relations among the different geological units. To the same end it is con-

venient to adopt a special name for each unit. The diagrammatic cross-section, figure 2, shows the units in their relative positions.

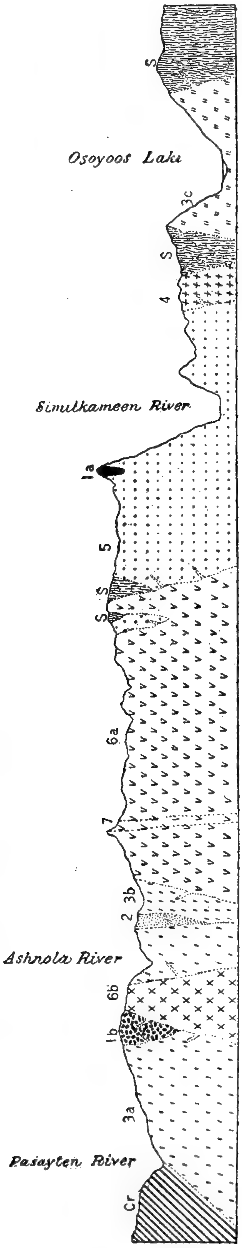

FIGURE 2.—*Diagrammatic east-west Section through the Okanagan Composite Batholith.*

S —Schists and associated Paleozoic rocks.
Cr—Pasayten Lower Cretaceous arkose sandstones.
1*a*—Chopaka peridotite.
1*b*—Basic complex.
2 —Ashnola gabbro.
3*a*—Remmel batholith, Western phase.
3*b*—Remmel batholith, Eastern phase.
3*c*—Osoyoos batholith.
4 —Kruger alkaline body.
5 —Similkameen batholith.
6*a*—Cathedral batholith, Older phase.
6*b*—Park granite stock.
7 —Cathedral batholith, Younger phase.

The components of the batholith are numbered in order of intrusion. Horizontal scale, one inch to ten miles; vertical scale, one inch to two miles. The vertical exaggeration makes contact lines generally too steep. On a natural scale the basic bodies, 1*a*, 1*b*, and 2, would be shown as extending deeper into the granites; the actual distortion is intended to illustrate the "pendant" nature of each body.

The most easterly component body occupies both slopes of Osoyoos Lake valley; it is the southern part of a great batholithic mass of granodiorite and may be called the Osoyoos batholith. The most westerly unit extends from Pasayten river to within a mile or so of Cathedral peak. It is also a batholith of granodiorite and seems to compose the cliffs of the conspicuous mount Remmel 5 miles south of the boundary. This mass may be called the Remmel batholith. Immediately to the eastward of the Remmel a third large batholith, this time composed of a quite different rock, true biotite granite, underlies all of the belt as far as Horseshoe mountain, on the divide between the Ashnola and main Similkameen rivers. This may be called the Cathedral batholith—named after the fine monolithic mountain occurring within the limits of the granite. The fourth principal unit lies between the Cathedral and Osoyoos batholiths; it is composed of a batholithic soda-rich hornblende-biotite granite which is trenched by the deep valley of the Similkameen river, and an appropriate name for it is Similkameen batholith. These four principal units make up five-sixths of the whole area here described.

The subordinate geological members (excluding dikes) within the batholithic area are eight in number.

The largest of these consists of apparently Paleozoic schists, quartzites, greenstones, and other rocks forming the ends of two tongues that enter the belt respectively from north and south (see figure 3). These rocks occur on the roughly tabular "Kruger mountain," and for present purposes may be called the Kruger schists. The two schist tongues adjoin the Osoyoos batholith and nearly cut it off completely from direct contact with other plutonic units in the belt.

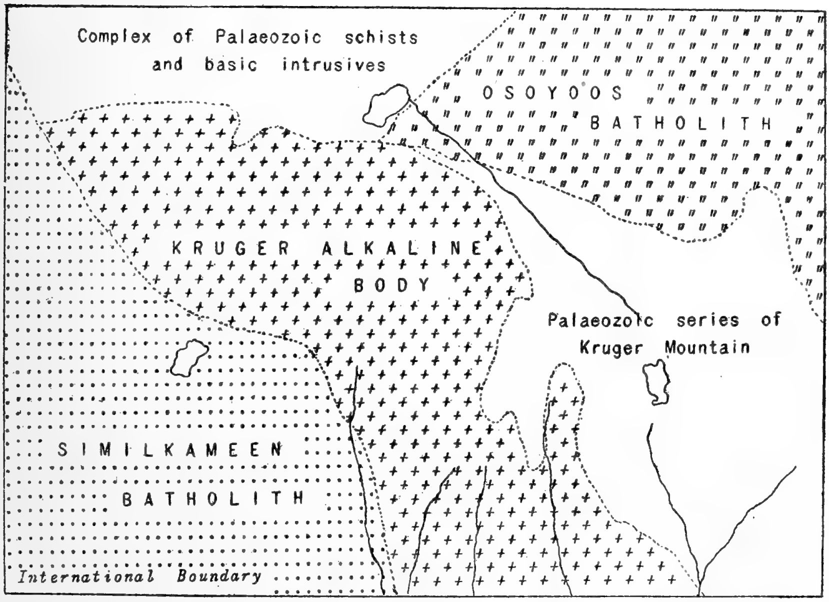

FIGURE 3.—*Ground Plan showing Relations of the Osoyoos, Similkameen, and Kruger igneous Bodies and the invaded Paleozoic Formations.*

Scale, 1 : 110,000.

Between the Kruger schists and the Similkameen batholith is a comparatively small area of highly composite intrusives belonging to the malignite and nepheline-syenite families (see figure 3). These crop out on the western summits of the Kruger Mountain plateau and may be referred to as the Kruger Alkaline body.

The Similkameen granite preserves what seem to be remnants of its once complete roof (see figure 4). Chopaka mountain is crowned with a large patch of schist very similar to the Kruger schist. This Chopaka schist is cut by a strong body of gabbro apparently transitional into pure olivine rock—the Chopaka Basic intrusives. The whole forms a huge

irregular block of roof rock almost completely surrounded and probably underlain by the Similkameen granite. Such a block, once a downwardly projecting part of a roof in stock or batholith, may be named a "roof pendant;" it is analogous to the pendant of Gothic architecture.

A brief digression on this conception may be permitted. Unusually fine examples of roof pendants are illustrated in the great slabs of bedded rocks interrupting the areas occupied by the batholiths of the Sierra Nevada. One of the most recent descriptions is published by Messrs Knopf and Thelen, following the lead of Lawson in a study of Mineral King, California.* Other examples, so well treated by Barrois, were found during the detailed geological survey of Brittany.† In all these and many other cases, and yet more clearly than on the 49th parallel, the masses of country rock (invaded formation) form respectively parts of a once continuous roof. The often perfect preservation of the regional strike in each of many examples very strongly suggests that these slabs have not sunk independently in their respective magmas. Such partial foundering would have almost inevitably caused some twisting of the block out of its original orientation. Granite and block have come into present relations because the magma, and not the block, was active. The point is of importance, as it bears on the mechanics of intrusion in these instances. It is further worthy of note that determination of roof pendants and their distribution may sometimes lead to the discovery of the approximate constructional form of batholiths.

A small pendant, composed of amphibolitic and micaceous schists and of quartzite, occurs on the north slope of Horseshoe mountain; another of similar constitution flanks the summit of Snowy mountain.

In all three cases the pendants appear in the highest portions of the batholith as now exposed in the belt; yet each block projects downward, deep into the heart of the granite mass.

A long slab of gabbro, ranging with the Cathedral fork of Ashnola river, is similarly a roof pendant to the Remmel batholith; it may be called the Ashnola gabbro (see figure 5). A still larger pendant, composed of gabbros and peridotites, lies in the Remmel batholith just west of the main valley of the Ashnola. On account of the extraordinary diversity of rocks and of rock structures in this pendant, it may be called the "Basic complex" (see figure 6).

Northeast of the complex is an elliptical stock of biotite granite, intrusive into both the Remmel granodiorite and the Basic complex. The

*Bulletin of the Department of Geology, University of California, vol. iii, no. 15, 1904, and vol. iv, no. 12, 1905.

†C. Barrois: Annales, Société Géologique du Nord, many volumes, especially vol. 22, 1894, p. 181.

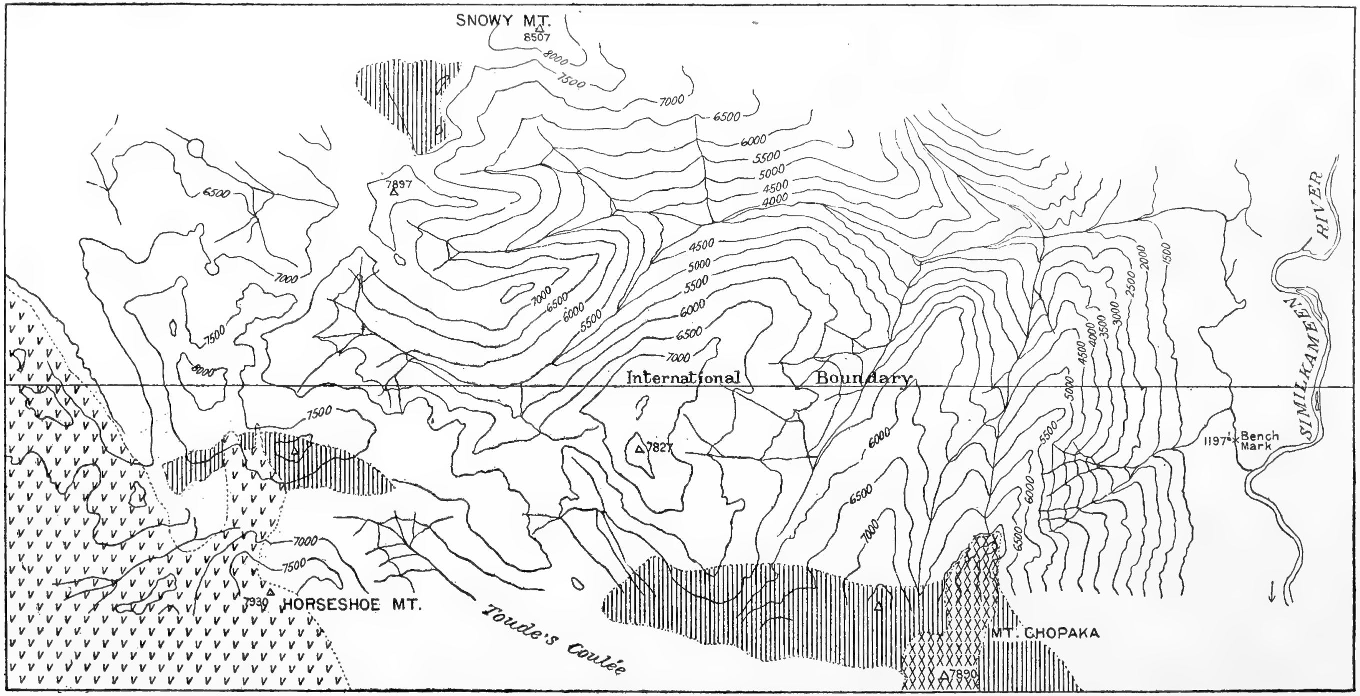

FIGURE 4.—*Map of the Similkameen Batholith, the Cathedral Granite Batholith, and the Chopaka basic intrusive Body.*

The Similkameen batholith (left blank) bears three roof pendants of schist (verticallining) and is cut by the Cathedral granite batholith (inverted carets). The Chopakabasic intrusive body (gabbro and dunite), cutting schists, but older than the Similkameen granite, is shown with crosses. Contour interval, 500 feet; scale, 1 : 120,000.

white, massive outcrops of the granite are very conspicuous on the northern spurs of Park mountain; the rock may be referred to as the Park granite (see figure 6).

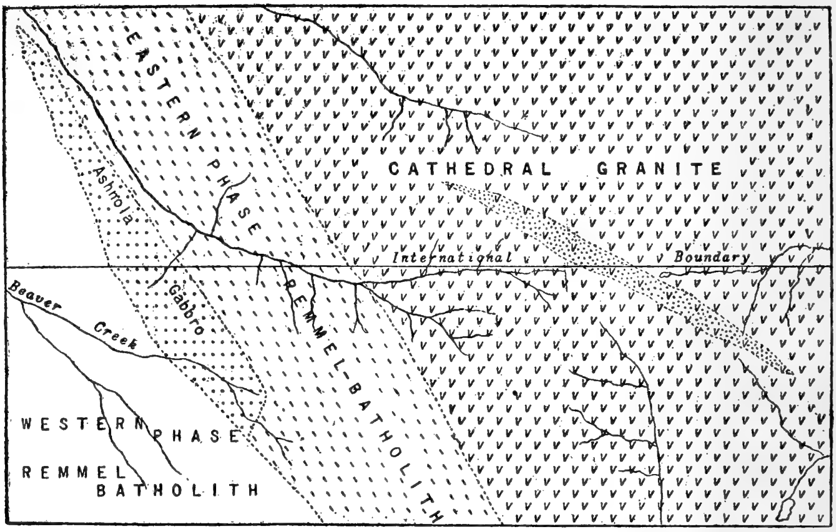

FIGURE 5.—*Ground Plan showing Relations of the Cathedral and Remmel Batholiths and the Ashnola Gabbro.*

The Younger phase of the Cathedral batholith is shown by stippling. The remarkably straight contact line of the Cathedral granite lies sensibly parallel to the gneissic banding in the Remmel batholith, Eastern phase. Scale, 1 : 120,000.

Within the 5-mile belt these various rock bodies occupy areas shown in the following table. The bodies are noted in order from east to west, beginning on the east:

	Square miles
Osoyoos batholith	50
Kruger schist	15
Kruger Alkaline body	9
Similkameen batholith	75
Chopaka schist	2
Chopaka basic intrusives	1¼
Horseshoe schist (pendant)	1
Snowy schist (pendant)	¾
Cathedral batholith	61
Remmel batholith	64
Ashnola gabbro (pendant)	1½
Basic complex (pendant)	6½
Park Granite stock	9
Total	296

The batholiths and the Kruger schist extend far to the north and to the south of the belt, so that the total area of each is much greater than is shown in the table. The figures given for all the other bodies represent nearly their respective total areas. Less than 7 per cent of the belt is underlaid by rocks not clearly plutonic in origin, and of that 7 per cent perhaps half is greenstone or other igneous rock. The 3 or 4 per cent of non-igneous rock is chiefly concentrated in the tongues of Kruger schist.

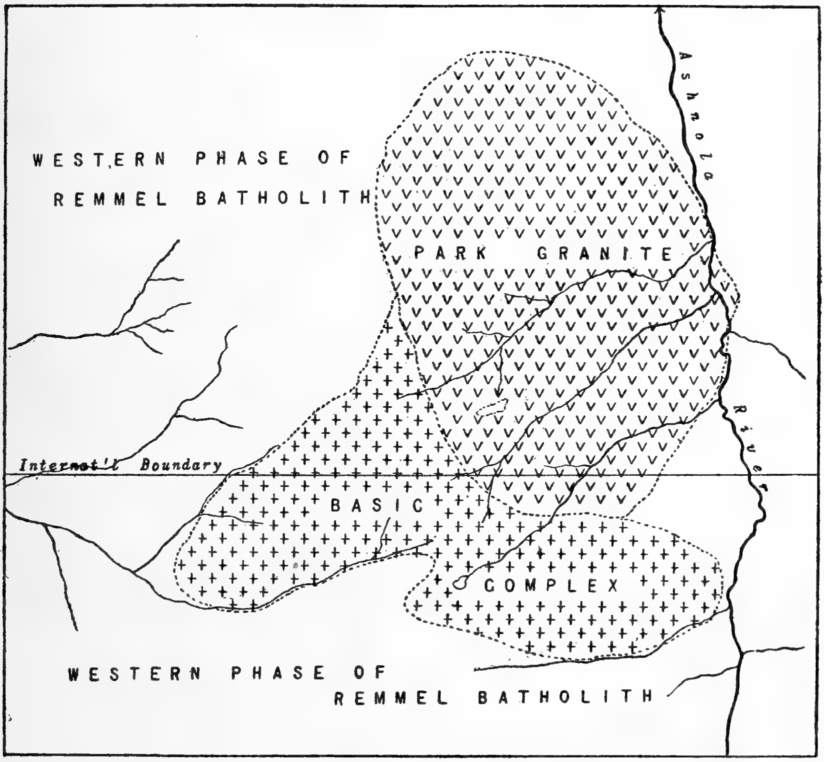

FIGURE 6.—*Ground Plan showing Relations of the Remmel Batholith, Park Granite, and Basic Complex.*

Scale, 1 : 120,000.

The tongues have been completely cut asunder by the plutonics; it is now possible to walk from one end of the belt to the other, the whole distance of 60 miles, and not once set foot on bed-rock which is other than of deep seated, igneous origin (see figures 2 and 3).

Unity of the Composite Batholith

Barring a few shreds and patches, the enormously thick pre-Paleozoic, Paleozoic, Mesozoic, and Tertiary sediments and schists represented in

the Cordillera elsewhere are wanting in this part of the Cascade system. With thicknesses running into tens of thousands of feet, they once unquestionably composed the Okanagan range, and of them the ancestors of these very boundary mountains were built. Erosion has removed some of the formations, attacking the earth's sedimentary crust from above. There is every reason to believe that perhaps even more of the old mountain substance was removed during the successive batholithic intrusions. Thus the sedimentary crust has also been attacked from beneath; its integrity has been destroyed through the displacing or replacing of sediments by igneous magma. In bringing about this gigantic result all the batholiths have acted together. Though they are of very different ages, their energies have been devoted to a common work. Their effects are so integrated that in causing the nearly complete disappearance of the ancient strata they have imitated on a larger scale what occurs with any homogeneous batholith. From this point of view the Boundary belt, stretching from the eastern contact of the Osoyoos batholith to the western contact of the Remmel batholith, forms a small segment of one composite batholith somewhat broader than the Okanagan range. To emphasize this primary fact, the title of the present paper has been chosen.

Petrography of the Composite Batholith

IN GENERAL

Before proceeding to a detailed statement of the structure and history of the composite batholith a brief petrographical description of its components will be necessary. The chemical study of these rocks has only begun, but, on account of their freshness and coarseness of grain, microscopic analysis has been found so trustworthy that the different types can be already sufficiently well classified for the purposes of this discussion of the general geology. Much of the usual petrographical detail has been omitted as not bearing directly on the main problems.

The rocks will be described as nearly as possible in the order of their respective dates of intrusion.

CHOPAKA BASIC INTRUSIVES

The basic and ultra basic intrusives of the Chopaka roof pendant have been described by Smith and Calkins as uralitic gabbro, serpentines, and pyroxenites. Within the area covered by the Commission map (figure 4), the present writer has found no pyroxenite, but has referred all the massive intrusives of the Chopaka pendant (excluding dikes) to two rock types and their metamorphic derivatives.

Most of the rock within the area is feldspathic and seems to belong to a fairly steady type—normal gabbro transitional to metagabbro. It is a dark gray-green, medium grained, hypidiomorphic granular rock, originally composed of essential labradorite (Ab_1An_1) and diallage and accessory apatite, with a little magnetite. Crush metamorphism, supplemented by ordinary weathering, has largely changed the diallage into actinolitic amphibole, both compact and smaragditic. The specific gravity of the least altered rock is 2.959, taken, as were all the other specific gravities to be mentioned, at room temperatures.

That common rock type is associated with a large body of a dark greenish gray, fine grained rock of which several specimens show the composition very clearly. It was originally made up entirely of granular olivine without any certain accessory constituent. No trace of chromite has been found. Serpentine, talc, tremolite, and magnetite are present in most of the thin-sections, but apparently in all cases as decomposition products of the olivine. The specific gravity of the rock varies from 3.100 to 3.173. It is a dunite without chromite.

The field relation of the gabbro and olivine rock has not been determined. They may belong to distinct intrusions or they may be due to differentiation within a single body. Though transitions seemed to appear in the actual outcrops, the search for final evidence in these rocks, crushed and obscured as they are, has so far proved unavailing. Analogous occurrences in other parts of the boundary belt suggest that gabbro and olivine rock were intruded at different dates.

ASHNOLA GABBRO

Throughout its 5 miles of length the Ashnola gabbro body is homogeneous in composition, but often varies abruptly in grain from medium to quite coarse. The color is uniformly a peculiar deep fawn, which is the dominating tint of the feldspar. This color is rather remarkable, as the rock proves under the microscope to be quite fresh, with feldspars of glassy clearness. The essential constituents are a green augite, often colorless in thin-section, brownish green hornblende, brown biotite, and labradorite, Ab_5An_6. Abundant apatite, some magnetite, and a very little interstitial quartz are the accessories. The structure in the original rock is the hypidiomorphic granular, though the augite is often, especially in the coarser grained phases, poikilitic. Regular intergrowths of the augite and hornblende are common. The rock is an augite-hornblende-biotite gabbro, the specific gravity of which averages 2.946.

Although the gabbro is older than the Remmel granodiorite and has shared in the great dynamic metamorphism which, as we shall see, has

profoundly affected the more acid rock, there is far less crushing action manifest in the gabbro than in the granodiorite. Gneissic structures were indeed sometimes seen in the ledges, but banding was never discovered and the granulation is seldom comparable to that of the Remmel. It is, moreover, suspected that some of the gneissic arrangement of minerals in the gabbro is due to fluidal alignment of its tabular feldspars in the original magmatic period. For some unknown reason the gabbro has resisted crushing and shearing better than the granodiorite.

BASIC COMPLEX

Petrographically and structurally, the Basic complex is perhaps the most steadily variable plutonic masses in the entire boundary section from the Great plains to the Pacific. It covers an area stretching from Ashnola river westward over Park Mountain ridge, a distance of 5 miles. The extreme north-and-south diameter is about 3 miles, and the total area is nearly 7 square miles. The Remmel granodiorite once completely surrounded the complex, which, as above noted, is in pendant relation to the batholith. The pre-Remmel extent of the complex was greater than the area now exposed; how much of it was destroyed during the Remmel intrusion it is impossible to say. The part thus remnant was still further diminished during the intrusion of the Park granite, which now, as illustrated on full 3 miles of contact line, projects strongly into the body of the complex. A large block of the latter formation, measuring about 400 yards in length by 200 yards in width, was found within the Park granite mass itself; it may represent a roof pendant in the stock, and thus a small analogue to the larger basic body in its relation to the Remmel batholith.

The Basic complex is made up of a remarkable assemblage of basic plutonic rocks of at least three different periods of intrusion. The oldest types are coarse grained. They include highly irregular bodies of hornblendite, which in the field is often seen to be transitional into a labradorite-bearing hornblende-augite peridotite; this in its turn merges into hornblende-augite gabbro. All of these rocks are believed to be of contemporary origin. Their occurrence is so sporadic that it is difficult to say how much of the whole basic area they really cover—possibly one-quarter of it by rough estimate. These rocks are cut by many large dikes and more irregular masses of hornblende-gabbro, augite-hornblende gabbro, and hornblende-biotite quartz gabbro. Such types are of medium to coarse grain. Their specific gravity varies from 2.873 to 2.986.

One 40-foot dike cutting the younger gabbros singles itself out as a unique petrographic type. It is an amphibole peridotite in which the olivine occurs in large, potato-shaped or ellipsoidal, coarse grained

nodules from $1\frac{1}{2}$ to 2 inches in diameter. These nodules are thickly and quite uniformly scattered through a coarse matrix of green hornblende. The dike is interesting on account of its peculiar structure, but is of little importance as a member of the complex as a whole; no other dike of the kind was found.

As there is no discoverable system in the differentiation of the earliest intrusive members, varying as they do most capriciously from ledge to ledge, so there is no discoverable system in the trends or occurrence of the countless later injections of the gabbros. The complication has been still further increased by the intrusion of thousands of narrow and broader dikes of granite. Much of the granite is apophysal or aplitic from the Remmel batholith; some of it is apophysal from the magma supplying the Park granite stock, while many dikes of acid pegmatite locally traverse the whole mass. The complication was finally made perfect through the enormous crushing which the Basic complex underwent, both during the intrusion of the granites and during the orogenic revolution when the Remmel granodiorite itself was sheared into banded gneisses.

In the shearing of the Basic complex its material was metamorphosed and, in part, it migrated. The mode of migration is believed to be that which will be briefly discussed in connection with the petrographic descriptions of the crushed Osoyoos and Remmel batholiths. The metamorphism has developed many schistose phases, among which hornblende-biotite-diorite gneiss (specific gravity, 2.766 to 2.863) and well foliated hornblendite are common.

As a result of this long and varied history, scarcely any two ledges within the area of the Complex accord in composition. The constitution of what appears to be the commonest phase of the Complex, the augite-hornblende gabbro, and the peculiar fawn color of its feldspar furnish a probable correlation of part of the whole mass with the Ashnola gabbro. There is no certainty of similar correlation with the basic rocks of mount Chopaka.

OSOYOOS GRANODIORITE BATHOLITH

Macroscopic and microscopic characteristics.—The original rock of the Osoyoos batholith is a typical medium to coarse grained granodiorite. The color is the familiar light gray characteristic of monzonites, granodiorites, and some other granular rocks rich in plagioclase. In the likewise fresh though somewhat metamorphosed phases the rock assumes a light greenish gray tint due to the dissemination of metamorphic biotite or to the abundant development of epidote. All phases weather light brownish gray. The essential constitutents are deep green hornblende,

brownish green biotite, orthoclase, quartz, and unzoned andesine, Ab_5An_3. The accessory minerals are apatite, magnetite, and titanite; none of these may be called abundant. Allanite in rather large amount is accessory in the basified contact zone. Colorless epidote is invariably present, but is regarded as of metamorphic origin. Where it becomes abundant the iron ore has partially or wholly disappeared; then probably entering into the composition of the epidote. Biotite is generally dominant over hornblende and plagioclase over orthoclase.

Along the eastern contact of the batholith the average plagioclase is labradorite, Ab_1An_1, and it so far replaces the orthoclase that the rock here verges on quartz diorite. In the hand specimen this somewhat basified contact phase is indistinguishable from the true granodiorite. The limits of the orthoclase-poor zone were therefore not closely fixed in the field. It is probable that the zone is not more than a few hundred yards in width, and that the original rock of the batholith was, in the large, homogeneous. A second exceptional phasal variation is founded on the disappearance of hornblende in rock that shows decided cataclastic structure, other constituents remaining the same as in the normal granodiorite. This phase—gneissic biotite granite rich in andesine—occurs sporadically in the heart of the batholith. Very possibly it is not of original composition, the hornblende having been removed through metamorphic action.

Dynamic and hydrothermal metamorphism of the granodiorite.—In the mapped area of the batholith scarcely a single outcrop can be found that does not show the powerful effects of intense orogenic strains. Even the most massive phases show, under the microscope, the varied phenomena of crushing stress—granulation, bending of crystals, undulatory extinctions, recrystallization, etcetera. Because of the crushing, the average rock is no longer the original rock. The granodiorite has been changed into several metamorphic types, of which three may be noted.

The commonest transformation is that into a biotite-epidote-hornblende gneiss, with essential and accessory constituents like those in the original granodiorite, but in somewhat different proportions. The color is light gray, with a green cast on surfaces transverse to the schistosity; parallel to the schistosity a dominant and darker green color is given by abundant fine-textured leaf aggregates of biotite. These aggregates are not simply crushed and rotated original mica foils, but, like the epidote, represent true recrystallization and the incipient migration of material within the granulated, plutonic rock. At the same time much of the original hornblende, apatite, and magnetite have been removed.

A second metamorphic type is a yet more highly schistose biotite-epidote gneiss often transitional into biotite schist. The essential constituents are biotite, epidote, orthoclase, andesine, and quartz. The accessories include very rarely apatite and magnetite, while titanite seems to have entirely disappeared along with the hornblende. Orthoclase seems here to be more abundant than plagioclase. The quartz and feldspars are intensely granulated and, with polarized light, are full of strain shadows. The rock is more richly charged with biotite than the hornblende-bearing gneiss.

The third metamorphic type occurs in immediate association with the gneiss just described, being interbanded with it. It is a fine grained, strongly schistose, dark greenish gray hornblende gneiss of basic character. The essential minerals are idiomorphic green hornblende and allotriomorphic feldspars in mosaic with considerable interstitial quartz; the last is hardly more than accessory. The feldspar is mostly unstriated and not easy of determination. Orthoclase seems to be dominant, but, as shown by extinctions on (010), approaches soda-orthoclase in composition. The plagioclase is possibly andesine. Titanite, apatite, and well crystallized magnetite are accessory in large amounts. The hornblende prisms are often twinned parallel to (010). That crystallographic plane now lies characteristically parallel to the plane of schistosity. Except for the soda content of the orthoclase, the minerals all appear to have the same characters as in the granodiorite.

This third phase occurs in zones of maximum shearing in the batholithic mass. It is believed to represent a new secondary rock formed by the recrystallization of the materials leached out of the other two metamorphic phases just noted and out of the granodiorite as it was crushed. The recrystallization either accompanied or followed the very closing stage of the orogenic crushing. This fact is demonstrated by the entire absence of granulation or even undulatory extinctions in the mineral components.

The probable history of the metamorphism may now be summarized. After the complete solidification of the original granodiorite, very intense crushing stresses affected the whole body. The straining and granulation of the minerals exposed them to wholesale solution, whether in water and other fluids mechanically inclosed in the rock or in fluids of exotic origin. This process of solution was hastened by the rise of temperature incident to violent crushing. All the minerals must have been affected, but it appears that the hornblende, biotite, magnetite, apatite, and titanite were most likely to be dissolved and so migrate with the fluids that slowly

worked their way through the rock in its mechanical readjustments.* Escape for the mineral-laden fluids was most ready in the zones of maximum shear. Thither the fluids were drawn, and there some of the dissolved material recrystallized so as to develop the darker colored bands of biotite-epidote gneiss, biotite schist, and hornblende gneiss.

Where the granulation was least the granodiorite retains nearly its original composition, though epidote may be formed; the specific gravity averages 2.746. Where the granulation was more pronounced, as in the first metamorphic type described, much of the hornblende, titanite, magnetite, and apatite have been leached out and abundant metamorphic biotite and epidote have formed; the result is a biotite-hornblende-epidote gneiss with a density less than that of the original granodiorite because of the loss in heavy constituents (specific gravity, 2.692). A further stage of granulation and energetic shearing led to the formation of perfect schistosity in rock made up of the quartz-feldspar ruins of the original rock, cemented by very abundant biotite and epidote—the biotite-epidote gneiss (specific gravity, 2.783). The fissures and fluid-filled cavities developed in the zones of maximum shear are now occupied by the strongly schistose hornblende gneiss (specific gravity, 2.939) and similar products of complete solution, migration, and subsequent complete recrystallization.

The granodiorite has thus become not only mechanically crushed, but to a large extent rendered heterogeneous. It is now not only gneissic, but banded in zones of new rock markedly varied in composition. The schistosity and banding everywhere agree in attitude; the strike varies from north 10 degrees west to north 75 degrees west, but over large areas, as indeed over the whole batholith east and west of Osoyoos lake, averages north 45 degrees west almost exactly. Neglecting minor crumplings, the dip varied from 70 degrees northeast to 90 degrees, averaging about 82 degrees northeast. This average attitude is close to that observed in the schists cut by the granodiorite, but represents an exceptional strike among the main structural axes of the Cordillera. It may be noted that shear-

*This conclusion has in this instance been deduced from the study of thin-sections. In general it accords with the results of experiment. Müller has found that in carbonated water hornblende and apatite are much more soluble than either orthoclase or oligoclase. Magnetite is less soluble than any of those minerals, but the relatively minute size of its crystals in granodiorite would allow of its complete solution and migration before the essential minerals had lost more than a fraction of their substance. It is also possible that magnetite would suffer especially rapid corrosive attack from fluid in which the chlorine-bearing apatite has gone into solution. Cf. R. Müller in Tschermak's Miner. und Petrog. Mittheilungen, 1877, p. 25.

ing is much more manifest on the east side of Osoyoos lake than on the west side.

REMMEL GRANODIORITE BATHOLITH

Physical and mineralogic characteristics.—There are many principal points of resemblance in composition between the extreme eastern and extreme western members of the composite batholith (see figure 2). The staple rock of the Remmel batholith is also a granodiorite. It is in color a light gray, weathering whitish to a light brownish gray; in grain, medium to rather coarse; in structure, eugranitic, though often somewhat porphyritic in look, through the development of large, black, lustrous biotites. These phenocrysts are sometimes perfectly idiomorphic, and then weather out in hexagonal plates about one centimeter in diameter. This commonest phase of the batholith is essentially composed of brownish green hornblende, biotite, quartz, orthoclase, and andesine which averages Ab_5An_3. Titanite is a fairly abundant accessory and is accompanied by apatite and by magnetite, often titaniferous. The specific gravity of this rock varies from 2.721 to 2.775, averaging 2.748.

Metamorphism.—Here again it is difficult to distinguish in the field any systematic variation of the original rock composition. If such variation ever were important, its discovery is rendered most uncertain through the profound metamorphic changes that have affected the batholith. Here, too, there has been tremendous shearing and crushing. A secondary gneissic structure has been formed over most of the batholith as exposed in the boundary belt. The shearing has been extraordinarily powerful in a north-south zone of the batholith running along the contact with the younger Cathedral batholith (see figure 5). In that zone, which extends westward as far as the Ashnola gabbro, the Remmel rock has been thoroughly changed from its original condition.

This "Eastern phase" of the Remmel is now remarkably banded. The broader bands are more or less massive biotite gneiss rich in oligoclase (Ab_6An_1), or orthoclase-bearing biotite quartz diorite gneiss. The color of these rocks is light gray, weathering white or light brown. Hornblende and titanite completely fail; apatite is accessory, but in small amount. A few reddish garnets are occasionally developed. There is seldom any indication of straining or crushing of the minerals constituting these bands. Microscopic study leaves the impression that the material of the bands has been wholly recrystallized. The specific gravity averages 2.651, and is thus considerably lower than in the normal granodiorite.

Alternating with the broad bands are very numerous dark green-gray, highly foliated zones of mica-gneiss and mica-schist, both very rich in bio-

tite, but bearing no hornblende. These zones were regarded in the field as located along planes of maximum shearing. They accord very faithfully in attitude with a strike of north 2 to 25 degrees west and a dip nearly vertical, but sometimes 75 degrees or more to the east-northeast—structural elements induced by regional orogenic movements in the Cordillera. It is improbable that the banding represents peripheral schistosity about the Cathedral batholith. The chief reason for excluding this view is that peripheral schistosity is lacking in the great Similkameen batholith, which is also cut by the Cathedral granite. It appears, on the other hand, that the Remmel batholith was already crushed and its banding produced before either the Similkameen or Cathedral granite was intruded.

Six-sevenths of the total area mapped in the Remmel batholith is underlaid by hornblende-bearing rock much more nearly identical with the original granodiorite. In fact the description of the granodiorite has been based on specimens taken from the more massive rock facies occurring in the larger area. The rocks of this "Western phase" are crushed and sheared, but distinctly less so affected than the mass forming the Eastern phase. Where strong shear zones occur in the Western phase they are occupied by dark greenish-gray, fine grained, fissile hornblende gneiss very rich in hornblende and similar to the secondary filling of shear zones in the Osoyoos granodiorite. Between these narrow shear zones the more normal rock usually shows mechanical granulation and fracture rather than extensive recrystallization.

Interpretations of the Eastern and Western phase.—Three interpretations of the two phases are conceivable. They may be supposed to be distinct intrusions of two different magmas; or, secondly, original local differentiation products in the one batholith; or, thirdly, distinguished in their present compositions because of the unequal dynamic metamorphism of a once homogeneous magma. Against the first view is the fact that the two phases, where in contact, seem everywhere to pass insensibly into each other. In favor of the third view are several facts which do not square with the second hypothesis, and the writer has tentatively come to the conclusion that the third hypothesis is the correct one. Among those facts are the following:

1. The Eastern phase covers that part of the Remmel body which has suffered the greatest amount of dynamic stresses exhibited either in the Remmel or in any other of the larger components of the Okanagan Composite batholith. It has been seen that the less intense though still notable dynamic metamorphism of the Osoyoos granodiorite led to the special excretion of most or all of the hornblende, apatite, magnetite, and titanite from that rock and the secretion of those leached-out compounds in the

free spaces of the shear zones. The biotite was similarly segregated, but its mobility was found to be considerably less than that of the hornblende. If the metamorphism had been yet more energetic in the Osoyoos body, the more soluble compounds would have been carried away completely and the whole would have crystallized in the form of acid biotitic gneiss banded with especially micaceous schists in the zones of maximum shear. Such appears to the writer to be the best explanation of the Eastern phase of the Remmel batholith.

2. The composition of the rock and the fact that, as above mentioned, it seems to have been thoroughly recrystallized into a strong, well knit, banded gneiss without cataclastic structure agree with this view.

3. The conclusion is substantiated in the study of more moderate shearing in the Western phase itself. There the strongly granulated and not recrystallized granodiorite shows impoverishment in the more mobile hornblende and accessories, which are segregated into intercalated, recrystallized bands. Thus hornblende-free, crushed rock indistinguishable in composition from the rock of the Eastern phase occurs sporadically in many local areas within the normal crushed granodiorite of the Western phase.

In summary, then, the Remmel granodiorite, gneissic biotite granite, biotite gneiss, biotite quartz diorite, and hornblende gneiss appear to belong to a single batholithic intrusion. This mass was originally a typical granodiorite. It has been dynamically and hydrothermally metamorphosed with intense shearing in zones trending north 20 to 25 degrees west. Over most of the batholith so far investigated these zones of physical and chemical alteration are not so well developed as to obscure the essential nature of the primary magma (Western phase). The shearing and transformation are much more profound in a wide belt elongated in the general structural direction north 25 degrees west. Here the rocks are well banded biotite gneisses, the material of which is residual after the deep seated, wholesale leaching of the more basic mineral matter from the crushed granodiorite (Eastern phase).

KRUGER ALKALINE BODY

Characteristics.—All the way from the Great plains to the Pacific waters nepheline rocks are extremely rare on the 49th parallel of latitude. The boundary section is now so far completed that it can be stated that in the entire section the Kruger body is the only plutonic mass bearing essential nepheline; it is likewise the most alkaline plutonic mass.

One of its principal characteristics is great lithological variability. It varies signally in grain, in structure, and above all in composition. All

the varietal rock types carry essential feldspars of high alkalinity—microperthite, microcline, soda-orthoclase, and orthoclase. Nepheline, biotite, brown-green hornblende, a pyroxene of the ægerine-augite series, and melanite complete the general list of essentials. Titanite, titaniferous magnetite or ilmenite, rutile, apatite, and acid andesine, Ab_5An_3 (the last entirely absent in most of the rock phases), form the staple accessories, though any one or more of the colored silicates may be only accessory in certain phases. Muscovite, hydronepheline, kaolin, calcite, epidote, and chlorite are secondary, but on account of the notable freshness of the rocks are believed to be due to crush-metamorphism more than to weathering.

According to the relative proportions of the essential minerals, at least ten different varieties of alkaline rock have been found in the body. These are—

Augite-nepheline malignite,
Augite-biotite-nepheline malignite,
Augite-biotite-melanite malignite,
Hornblende-augite malignite,
Augite-nepheline syenite,
Hornblende-nepheline syenite,
Biotite-melanite-nepheline syenite,
Augite-biotite-nepheline syenite,
Porphyritic augite syenite,
Porphyritic alkaline biotite syenite.

There is a question as to how far this list of varieties actually represents the original magmatic variation within the body. The evidence is good that the augite and hornblende and a part of the biotite, along with the feldspars and nepheline, crystallized from the magma. It is not certain in the case of melanite which, in the Ontario malignite, as described by Lawson, appears to be a primary essential.* Microscopic study shows that much of the melanite in the Kruger rocks is of magmatic origin, but that perhaps much more of it has replaced the pyroxene during dynamic metamorphism. In such cases the pyroxene, where still in part remaining, is very ragged, with granular aggregates of the garnet occupying the irregular embayments in the attacked mineral. A further stage consists in the complete replacement of the augite by the melanite aggregates which are shot through with metamorphic biotite. These peculiar reactions between the pyroxene and the other components of the rock are widespread in both syenite and malignite.

All the phases so far studied in this natural museum of alkaline types can be grouped in three classes—granular malignites, granular nepheline syenites, and coarsely porphyritic alkaline syenites. The malignitic varieties are always basic in look, dark greenish-gray in color, and medium to coarse in grain (specific gravity, 2.757 to 2.967). The nepheline syenites are rather light bluish-gray in tint, medium to fine grained, and

*Bulletin, Dept. of Geology, University of California, vol. 1, 190.

break with the sonorous ring characteristic of phonolite (specific gravity, 2.606 to 2.719). The third class of rocks is much less important as to volume; they are always coarse in grain, of gray color, and charged with abundant tabular phenocrysts of microperthite which range from 2 to 5 centimeters in length. These phenocrysts as well as the alkaline feldspars of the coarse groundmass are usually twinned, following the Carlsbad law—a characteristic very seldom observed in the malignites or nepheline syenites.

The nepheline syenites often send strong apophysal offshoots into the malignites, but such tongues are highly irregular and intimately welded with the adjacent basic rock as if the latter were still hot when the nepheline syenites were intruded. Moreover, there are all stages of transition in a single broad outcrop between typical malignite and more leucocratic rock indistinguishable from the nepheline syenite of the apophyses. Similarly, even with tolerably good exposures, no sharp contacts could be discovered between the coarse, porphyritic syenites and the other phases. The porphyritic rocks almost invariably showed strong and unmistakable flow structure, evidenced in the parallel arrangement of undeformed phenocrysts; these generally lie parallel to the contact walls of the body as a whole. The phasal variety of the Kruger body and the field relations of the different types seem best explained on the hypothesis that the phases are all nearly or quite contemporaneous—the product of rapid magmatic differentiation accompanied by strong movements of the magma. These movements continued into the viscous stage immediately preceding crystallization.

The average composition of the whole Kruger body is probably that of a malignite transitional into true nepheline syenite; its specific gravity, about 2.750.

Metamorphism.—Few of the specimens collected are free from signs of crushing. This has sometimes induced a decided gneissic structure, and almost always the microscope shows fracture and granulation. The abundant development of metamorphic melanite and biotite and the occasional production of large poikilitic scapolites indicate some recrystallization through dynamic metamorphism. The abundance of microcline and the generally subordinate character of the orthoclase is another, yet more familiar, relation brought about through the crushing. The mechanical alteration of these rocks is far from being as thorough as in the case of the Osoyoos batholith. This is a principal reason for believing that the alkaline mass was intruded after the Osoyoos granodiorite had been itself well crushed. No other definite field evidence for or against that view has been discovered. However, the magmatic relationships between the

uncrushed Cathedral and Similkameen batholiths and the Kruger body also suggest that all three belong to one eruptive epoch of several stages—an epoch long subsequent to the intrusion of the Osoyoos and Remmel batholiths. The Similkameen granite is clearly intrusive into the Kruger alkalines, which may owe their strained and often granulated condition to the forceful entrance of that immense and immediately adjoining body of granite (see figure 3).

Three complete chemical analyses of types from the body have been made, which clearly show that the rare family of malignites is here represented on a large scale. The analyses are not given or discussed in this paper, as their details are scarcely relevant to the main purposes of the geological inquiry.

SIMILKAMEEN GRANITE BATHOLITH

General character and mineral constituents.—The staple rock of the Similkameen batholith is a medium to coarse grained, light pinkish-gray soda granite. Its essential constituents are hornblende, biotite, quartz, basic oligoclase (averaging Ab_7An_3), and the alkaline feldspars, microperthite, microcline, microcline-microperthite, and orthoclase. The last named is characteristically rare; microperthite is the most abundant of the alkaline feldspars. The accessories are magnetite, apatite, and beautifully crystallized titanite. Allanite is a rare accessory; epidote is occasionally present, but apparently is secondary. The structure and order of crystallization are normal for granites, though microperthite is often in phenocrystic development. A determination of the weight percentages of the constituents found in a type specimen collected in the Similkameen River valley was made by the Rosiwal method. It gave:

	Per cent
Oligoclase	29.8
Microperthite	27.0
Quartz	22.0
Orthoclase and microcline	6.7
Biotite	5.5
Hornblende	4.2
Magnetite	1.8
Titanite	1.1
Epidote	1.1
Apatite	.8
	100.0

This calculation is rough, though it gives a calculated specific gravity for the rock (2.682) that checks well with the observed specific gravity (2.693).

For many square miles together the great central portion of the batholith is composed of this rock—a soda-rich biotite-hornblende granite of an average specific gravity of 2.706.

At the head of Toude (or Toat) coulee the rock of a large area within the batholith is generally porphyritic and distinctly finer grained than the staple granite, the specific gravity averaging 2.675. The phenocrysts are poikilitic microperthites bearing many inclusions of the other constituents. In the specimens so far examined, orthoclase tends to dominate over microperthite. Near the contacts with the normal equigranular rock, oligoclase replaces the alkaline feldspars to a great extent; yet this phase is always poorer in both hornblende and biotite than the normal phase, which is thus slightly the more basic rock. The finer grained phase was seen at several places only a few feet from the coarser; the contact is there sharp, but the absolute relation between the two phases could not be determined. It is highly probable that both are of nearly contemporaneous origin, the intrusion of the porphyritic phase having followed that of the equigranular rock by a short interval, as if in consequence of massive movements in one slightly heterogeneous, partially cooled magma. The porphyritic phase often shades into the other so imperceptibly that a separation of the two phases on the map is a matter of great difficulty, if not of impossibility.

The material of the batholith is further varied by rather rare basic segregations. These have the composition of hornblende-biotite diorite, being made up of the minerals of earlier generation in the host.

Contact basification.—Much more important products of differentiation, as shown by microscopic analysis, are illustrated in a wide zone of contact basification. Here there occur several related types of alkaline or subalkaline syenites. In specimens collected along the contact with the Kruger alkalines, quartz nearly or altogether fails, biotite is absent, and abundant diopsidic augite accompanies the essential hornblende. The feldspars are the same as in the staple rock, with basic oligoclase, Ab_2An_1, yet more abundant than there. Zircon is added to the list of accessories. These facts and the general habit of the rock relate it both to monzonite and to genuine alkaline syenites. The chemical analysis closely resembles that of the typical rock from Monzoni, except that the soda is strongly dominant over the potash (4.60 per cent of Na_2O to 3.00 per cent of K_2O). This basic phase may be called an augite-hornblende soda monzonite of a specific gravity of 2.800–2.819. It is known to extend at least 1,200 yards from the main eastern contact of the batholith. It is an open question as to how far this basification is due to absorption of ma-

terial from the adjacent malignite-syenite series and how far to ordinary spontaneous differentiation along the batholith walls.

On the contact with the quartzites and schists of mount Chopaka the basification is less pronounced; compared to the staple granite, this phase is poor in quartz and rich in oligoclase-andesine and hornblende. It may be called a hornblende-biotite soda monzonite of a specific gravity of 2.712–2.748.

For a half mile or more northwest of the contact with a large body of schist forming the Horseshoe pendant (figure 4) the batholith exhibits a third basic phase. There is an almost complete disappearance of alkaline feldspars, other characters of the rock remaining essentially like those of the granite. This phase is a hornblende-biotite quartz diorite of a specific gravity of 2.736. Here again there is doubt as to the exact cause of the basification. The Horseshoe pendant is largely amphibolitic in composition, and it is possible that assimilation of material from these schists is partly responsible for the development of the quartz diorite.

CATHEDRAL GRANITE BATHOLITH

Character of the material.—The youngest of the batholithic intrusives is petrographically the simplest of all. Its material is singularly homogeneous, both mineralogically and texturally. The rock is a coarse grained, light, pinkish-gray biotite granite of common macroscopic habit. The essential minerals are microperthite, quartz, oligoclase, Ab_3An_1, orthoclase, and biotite; the accessories, apatite and magnetite, with rather rare titanite and zircon. The order of crystallization is normal for granites. Sometimes, and especially along contact walls, the rock is porphyritic, with the microperthite developed in large idiomorphic and poikilitic phenocrysts, which, as described by Calkins, weather out with a retention of the crystal form.

A determination of weight percentages by the Rosiwal method afforded the following result:

	Per cent
Microperthite	40.3
Quartz	35.7
Oligoclase	11.0
Orthoclase	7.0
Biotite	5.0
Magnetite and titanite	.7
Apatite	.3
	100.0

It is seen by inspection of the weight percentage tables that this granite carries more silica than does the granite of the Similkameen batholith, which in its turn is more acid than the granodiorites.

The great bulk of the batholith is thus composed of biotite soda granite (specific gravity, 2.631).

A local varietal phase, bearing dark green hornblende as a second essential, was found in the contact zone, 400 yards or more in width, alongside the Similkameen hornblende-biotite granite; here there may also be some slight enrichment in oligoclase at the expense of the microperthite. Neither hornblende nor biotite is abundant. The specific gravity of this phase is 2.644. The cause of the basification must once more be left undecided; it may lie in assimilation, in differentiation, or in both.

The ordinary basic segregation is notably rare in this batholith. A few, with the composition of biotite quartz diorite, were seen, but they seldom exceeded a few inches in diameter.

Younger phase.—The coarse granite had been intruded, and apparently so far cooled that joints had developed within its mass, when a second eruptive effort thrust a great wedge of nearly identical magma into the heart of the batholith. This may be called the Younger phase of the Cathedral batholith. It forms a large dike-like mass 3½ miles long and averaging 400 yards in width; its length runs about north 60 degrees west and lies parallel to a system of master joint planes within the Older phase.

The Younger phase has the same general color as the coarse granite, but is finer grained, more regularly porphyritic, and more acid. The microperthite of the older granite is here largely replaced by orthoclase and microcline, both sodiferous; at the same time the plagioclase is more acid, being oligoclase near Ab_8An_1. The accessories are the same as in the coarse granite, but are much rarer. Biotite, too, is here less abundant. The weight percentages are approximately:

	Per cent
Quartz	38.8
Orthoclase and microcline	33.4
Oligoclase	17.6
Microperthite	5.8
Biotite	3.5
Magnetite	.6
Apatite	.3
	100.0

The Younger phase approaches an aplitic relation to the older. The contacts between the two were seen at several points; they are sharp, yet

the two rocks are closely welded together, and it seems probable that the coarser granite was still hot when the younger granite was injected.

PARK GRANITE STOCK

The Park Granite stock measures 4 miles in length by 2½ miles in width (figure 6). This granite is coarse, unsqueezed, and in almost all respects resembles macroscopically the Older phase of the Cathedral batholith, of which the Park granite seems to be a satellite. Under the microscope the rock differs from the coarser Cathedral granite chiefly in the entire replacement of microperthite by orthoclase; so that this granite is a normal biotite granite rather than a soda granite. The greater homogeneity of the dominant feldspar may explain the fact that the Park granite is somewhat more resistant to the weather than the Older phase of the Cathedral batholith. A few prisms of dark green hornblende are accessory in much the same proportion as in the Younger phase of the Cathedral. With these exceptions, both essential and accessory constituents are, in individual properties and in relative amounts, practically identical in the type specimens of stock and the Older phase of the batholith. The specific gravity of the Park granite is 2.673.

A second, very small boss of the Park granite occurs within the mass of the Remmel batholith some 5 miles west-southwest of the Park Granite stock. This boss is circular in plan and measures not more than 250 yards in diameter.

Geological Relations

The Okanagan mountains are among the most accessible in the whole trans-Cordilleran section along the 49th parallel. Even without a trail, horses can be taken to almost any point in the 5-mile belt. Owing partly to mere altitude, partly to the general climatic conditions, the summits are often well above the timber line, while the mountain flanks are clad with the woods of beautiful park lands. Another special advantage in determining geological relations consists in the freshness of the rocks, which have been heavily glaciated and have not been seriously injured by secular decay. With a little searching, excellent and often remarkably perfect exposures of every formation and of its more important contacts can usually be discovered. Each of the principal field relations now to be noted has been determined not from one contact alone, but through the accordant testimony of several favorable localities.

The oldest rocks within the batholithic area are the Kruger schists, with their associated basic intrusives, and the roof pendants of the Similkameen batholith (figures 2, 3, 4, 5, and 6). Without doubt these rocks

are comparable in age to quite similar formations forming the eastern limit of the Okanagan Composite batholith as a whole. From the eastern contact of the Osoyoos batholith eastward for nearly 20 miles the rolling mountain slopes are chiefly underlain by an intensely folded, mashed, and metamorphosed group of quartzites and phyllites, in which there occur intercalations of ancient diabasic rocks with occasionally strong pods of semi-crystalline limestone. These rocks had been crushed and dynamically metamorphosed before the intrusion of the oldest component batholith of the Okanagan range. Again and again since that early period of metamorphism the same stratified formations have been gripped in the writhing paroxysms of Cordilleran revolutions. So extensive has been the crumpling, shearing, and overturning that it must ever remain a matter of the utmost difficulty to reduce the series to stratigraphic order. Within the belt covered by the Boundary Commission it has proved so far impossible to secure either a bottom or top to the series. Fossils entirely fail. All that can be said concerning the age of the metamorphosed sediments is that they are almost certainly Paleozoic. In many respects they have lithological characters like those of Carboniferous formations both in California and British Columbia. It is very possible that portions of the series are still older. From analogies drawn from better known regions in the Cordillera, it is believed that the basic intrusives of mount Chopaka and of the great schist-sediment area east of Osoyoos lake are likewise of Paleozoic age, though of course younger than the schists and quartzites which they cut.

Since the rocks of the Basic complex are crushed and metamorphosed in as extraordinary degree as any of the above-mentioned formations, the complex is regarded as a Paleozoic parallel to the Chopaka basic intrusives, though perhaps not strictly contemporaneous with the latter. For a reason already noted, the Ashnola gabbro is possibly to be correlated in age with the larger part of the Basic complex.

The mode of intrusion and therewith the structural relation of each of these basic masses to its original country rock can not be declared. In the case of two of them—the Basic complex and the Ashnola gabbro—not a fragment of the invaded formation has been found. It is, however, improbable that any of these bodies ever had batholithic dimensions. Their present isolated positions and the analogy of other similar gabbro-peridotite bodies in the Cordillera suggest that each of them was of relatively small size. The Chopaka body cross-cuts the bedding of the quartzites and schists. It may be in "chonolithic" relation to these—that is, it may be an irregularly shaped mass magmatically injected into the bedded rocks, but not, as with a true laccolith, following bedding planes.* The

*Cf. Journal of Geology, vol. xiii, 1905, p. 498.

contacts are insufficiently shown to warrant any decision in the case. The Ashnola gabbro may similarly be the residual part of an injected body. That it was a comparatively small body is suggested by an apparent flow structure still preserved even in the medium grained facies of the gabbro. In a batholithic rock of that texture, fluidal arrangement of the minerals is very rare. The infinitely diverse composition and structure of the Basic complex much more clearly points to a non-batholithic origin. One imagines rather that the lithological and structural complication are in this case such as might appear at the deep-seated focus of an ancient volcanic area. The geological record has, however, been too largely obscured or destroyed that any of these hypotheses concerning the basic intrusives can be verified.

One fact is certain, that all of the bodies are older than the granites by which they are surrounded. Their contacts with the granites are the sharpest possible; gabbro or peridotite is pierced by many typical apophyses of granite or granodiorite which has often shattered the basic rocks and isolated blocks which now lie within the basic body. Here there is no question of the gabbros being differentiation products from their respective granitic magmas, as so often described in the granodiorite batholiths of California.* There remains, secondly, the conclusion that these basic intrusives were probably not of batholithic size. They show that some time before the real development of the Okanagan Composite batholith began, a basic, subcrustal magma was erupted on a limited scale—possibly in the form of stocks, possibly in the form of chonoliths.

Undoubted batholithic intrusion began with the irruption of the granodiorites. The familiar phenomena of such intrusion are exhibited along the contacts of the Osoyoos batholith. For several hundred yards from the igneous body the phyllites have been converted into typical, often garnetiferous, mica schists. This collar of thermal or hydrothermal metamorphism would doubtless be yet more conspicuous if at the time of intrusion the Paleozoic series had not already been partly recrystallized in the earlier dynamic metamorphism of the region.

The Remmel batholith is, as we have seen, composed of granodiorite similar in original composition to the rock of the Osoyoos batholith. Fossiliferous Lower Cretaceous arkose sandstones, grits, and conglomerates overlie the Remmel unconformably. The materials for these rocks were in part derived from the secular weathering of the Remmel granodiorite, the weathering being accompanied by rapid deposition of the debris in a local sea of transgression. Arkose sandstones, which alone measure more than 10,000 feet in thickness, were thus deposited in a

*See many of the Californian folios issued by the U. S. Geological Survey.

down-warped marine area just west of the Pasayten river. To furnish such a volume of sediment, there would appear to have been in the region, preferably to the eastward of the Pasayten, a much larger area of granitic rocks than is now represented in the Remmel and Osoyoos batholiths combined. It is possible, indeed, that at that time these two batholiths were part of one huge mass of granodiorite which largely occupied the site of what is now the Okanagan Composite batholith. Both Remmel and Osoyoos granodiorites have suffered profound metamorphism, so similar in its effects in the two rock masses that it may most simply be attributed to the same period of orogenic disturbance. The systematic parallelism of the shear zones in each batholith and the fair accordance in trends of the zones occurring in both batholiths suggest that there has been but one such revolutionary disturbance since the batholiths were irrupted. If this be true, the period is identical with the post-Lower Cretaceous epoch, when the Pasayten Lower Cretaceous was thoroughly folded and crushed into its present greatly deformed conditions in the Hozomeen range.

The Osoyoos and Remmel batholiths are thus probably contemporaneous probably both post-Carboniferous and certainly pre-Cretaceous. It is best to correlate them with similarly huge bodies of granodiorite determined as Jurassic in California and southern British Columbia.

It should be noted that, since the Remmel granodiorite disappears under the cover of Lower Cretaceous at the Pasayten, 60 miles is the minimum width of the Okanagan Composite batholith.

In the latter part of the Jurassic the granodiorite batholith was uncovered by erosion, then down warped to receive a vast load of quickly accumulated sediments until more than 30,000 feet of the Pasayten Cretaceous beds were deposited in the area between the Pasayten and Skagit rivers. As yet there is no means of knowing how far this filled geosynclinal extended to the eastward, but it doubtless spread over most of the area now occupied by the Okanagan Mountain range.

The prolonged sedimentation was followed by an orogenic revolution that must have rivaled the mighty changes of the Jurassic. The Cretaceous formation was flexed into strong folds or broken into fault blocks in which the dips now average more than 45 degrees and frequently approach verticality. It was probably then that the Jurassic granodiorites were sheared and crushed into banded gneisses and gneissic granites essentially the same as the rocks now exposed in the Remmel and Osoyoos batholiths. No sediments known to be of later age than the Lower Cretaceous have been found in this part of the Cascade system; hence it is not easy to date this orogenic movement with certainty. Dawson has already summarized the evidence going to show that many, perhaps all,

parts of the Canadian Cordillera were affected by severe orogenic stresses at the close of the Laramie period.* It is probable that the stresses were even greater along the Pacific coast than they were in the eastern zone, where the Rocky Mountain system was built.. To this post-Laramie, pre-Eocene epoch the shearing of the granodiorites may be best referred.

We have seen that there are good reasons for considering the composite Kruger Alkaline body as younger than the granodiorites. It is clearly older than the Similkameen granite, as proved by the discovery of fine apophyses of the granite cutting the nepheline rocks. The Kruger body once extended some distance farther west over an area now occupied by the granite. The former, when first intruded, was an irregularly shaped mass without simple relation to its country rocks, the Paleozoic complex. The mode of intrusion was that of either a stock or a chonolith. In the first case the body was subjacent and enlarged downwardly; in the second case it was injected and its downward cross-section may have diminished. As with so many other instances, the contacts are too meagerly exposed to fix the true alternative. The nepheline syenite was in part injected into the nearly contemporaneous malignite. The common fluidal structure of these rocks also points to a mode of wedge intrusion more like that of dike or laccolith than like that of a stock. The Kruger body may thus represent a composite chonolith, but the problem of its style of intrusion must remain open. The date of the intrusion was post-Laramie. The alkaline magma may have been squeezed into the schists while mountain building progressed or after it had ceased. The crushing and incipient metamorphism of this body is on a scale more appropriate to the thrust resulting from the irruption of the younger Similkameen granite than to the more powerful squeezing effect of the post-Laramie mountain building.

True batholithic irruption was resumed in the replacement of schists, nepheline rocks, and possibly much of the granodiorite by the Similkameen batholith. This great mass is uncrushed, never shows gneissic structure, and has never been significantly deformed through orogenic movements.

The composite batholith received its last structural component when the Cathedral granite finally cut its way through Remmel granodiorite, Similkameen granite, remnant Paleozoic schists, and possibly through Cretaceous strata, to take its place as one of the most imposing geological units in the Cascade system. The field proofs are very clear that the Similkameen granite was solid and virtually cold before this last granite ate its way through the roots of the mountain range. See the large in-

*Bull. Geol. Soc. Am., vol. 12, 1901, p. 87.

trusive tongues cutting the schist pendant north of Horseshoe mountain, as illustrated in figure 4. The contacts between the two batholiths are of knife-edge sharpness. The younger granite, persisting in all essential characters even to the main contacts, sends powerful apophyses into the older granite, exactly as if the two batholiths were in age several geological periods apart. Both are of Tertiary age and bear witness to the tremendous plutonic energies set free in a late epoch of Cordilleran history. Quietly, but with steady, incalculable force, this youngest magma worked its way upward and replaced the invaded rocks. During the same time the satellitic Park granite was irrupted with the stock form and relations.

Smith and Mendenhall have described a large batholith of "quartz monzonite or quartz diorite" (granodiorite?) intrusive into Miocene argillites at Snoqualmie pass in the northern Cascades and 100 miles southwest of Osoyoos lake.* This is one of the youngest batholiths yet described in the world. The more basic phases of the Similkameen batholith present similarities to the rock at Snoqualmie pass. It is thus possible that the Similkameen granite was irrupted in late Miocene or even in Pliocene time; the Cathedral batholith is yet more recent.

Résumé of the Geological History

The stages in the petrological development of the Okanagan Composite batholith as it now exists may now be summarized. We begin with the oldest stage that is of importance in this particular history:

1. Intense metamorphism of Paleozoic and earlier formations (probably) in the late Carboniferous period, accompanied or soon followed by the intrusion of the Chopaka, Ashnola, and Basic Complex gabbros and peridotites in chonolithic (?) or other relations. Differentiation within these bodies.

2. In Jurassic time, batholithic irruption of the Osoyoos and Remmel granodiorites. Contact differentiation of quartz diorite in the former, at least.

3. Rapid denudation of the granodiorite batholiths in the late Jurassic; local subsidence of their eroded surface beneath the sea, there to be covered with a thick blanket of Cretaceous sediments which are in part composed of debris from the granodiorite itself.

4. At the close of the Laramie period, revolutionary orogenic disturbance, shearing and crushing the granodiorites and basic intrusives. In the former, development of strong crush-foliation and banding with the

*Bull. Geol. Soc. Am., vol. 11, 1900, p. 223.

formation of new rock types, including biotite-epidote-hornblende gneiss, biotite-epidote gneiss, basic hornblende gneiss, biotite schist, hornblende schist, and recrystallized biotite granite-gneisses; in the basic intrusives, development of metagabbro and various basic (dioritic) gneisses and hornblendites. Simultaneous strong folding of the Cretaceous strata.

5. Either accompanying or following the post-Laramie deformation, the (chonolithic?) intrusion of the Kruger Alkaline body, which consists of nearly synchronous masses of nepheline syenite and malignite. In these at least ten different rock types, due in part to the splitting of an alkaline magma and in part to later rynamic metamorphism, have been recognized.

6. In Tertiary time the batholithic irruption and complete crystallization of the soda-rich Similkameen hornblende-biotite granite, its contact basification forming soda-monzonites and quartz diorites.

7. In later Tertiary time the batholithic irruption of the Cathedral biotite granite, Older phase, accompanied by the intrusion of the Park Granite stock, immediately followed by the injection of the Cathedral granite, Younger phase, within the body of the Older phase.

8. Removal by denudation of much of the cover over each intrusive body. Complete destruction of the Cretaceous cover except at the Pasayten River overlap. Certain dikes of olivine basalt injected into the Cathedral and other granites are apparently of Pleistocene age and represent the latest products of eruptive activity in the Okanagan range. These dikes are quantitatively of no importance in the development of the composite batholith itself.

Sequence of the eruptive Rocks

The summary has been recast so as to show more conveniently the order in which the various intrusions took place. The resulting table also contains a column showing the average specific gravity of the rock composing each eruptive body. These values, as is the case with all values given in this paper, were obtained by the use of entire hand specimens varying in weight from a half pound to two pounds. A large, sensitive bullion balance was found to be specially adapted to the purpose. This method has several advantages over rapid methods in which only small rock fragments are used. The larger the specimen weighed, the greater is the probability that the average density is secured and the smaller the chance for error through adhering air bubbles. A third reason for preferring this method is that the shape of a trimmed hand specimen need never be impaired in obtaining the rock chip usually employed for specific gravity determinations.

The observations were made at room temperatures:

Geological age.	Stage of intrusion.	Name of body.	Observed variation in specific gravity.	Average specific gravity.
Late Paleozoic (Carboniferous?)	1*a*.	Chopaka basic intrusives.	Gabbro, 2.959... Dunite, 3.173....	3.074
	2.	Ashnola gabbro	2.935–2.957.......	2.946
	1*b*.	Basic complex (metamorphosed).	2.766–ca. 3.100....	2.872
Jurassic............	3*c*.	Osoyoos Granodiorite batholith (metamorphosed).	2.692–2.939.......	2.746
	3*a* and 3*b*.	Remmel Granodiorite batholith; two principal phases due to metamorphism.	2.655–2.680...	2.720
Close of the Laramie, or Tertiary.	4.	Kruger Alkaline body.	Malignites, average 2.824. Syenites, average 2.675.	2.750
Tertiary............	5*a* and 5*b*.	Similkameen Granite batholith; two principal phases.	2.660–2.819.......	2.706
	6*a*.	Cathedral Granite batholith, Older phase.	2.621–2.644......	2.631
	6*b*.	Park Granite stock.....	....	2.673
	7.	Cathedral batholith, Younger phase,	....	2.608

Magmatic stages 1*a* to 3*b*, inclusive, afforded non-alkaline rocks rich in hornblende and carrying plagioclase, either basic or of medium acidity, as the dominant feldspar. These bodies may be regarded as belonging to one consanguineous series. Magmatic stages 4 to 7, inclusive, afforded alkaline rocks bearing nepheline in the most basic phases and microperthite (orthoclase in 6*b* and 7) as the dominant feldspar throughout the series except in certain basified contact zones. This group belongs to a second consanguineous series. Each series shows a steady increase of acidity and decrease of density as its different members were successively intruded. With the exception of one abnormal stage, the same double law underlies the entire magmatic succession. This exception is found in the Kruger Alkaline body, which in almost every other respect as well

is anomalous among these masses. The comparatively small size and the isolation of the nepheline-rock body and its structural characteristics and relations appear to warrant the conclusion that it is the product of a very special differentiation. Neither malignite nor nepheline syenite seems to represent a *general* subcrustal magma in the region at any time. It is different with the small bodies of gabbro in the roof pendants of the batholiths. The repeated occurrence of gabbro, not only in the Okanagan range, but throughout the length and breadth of the Cordillera, as

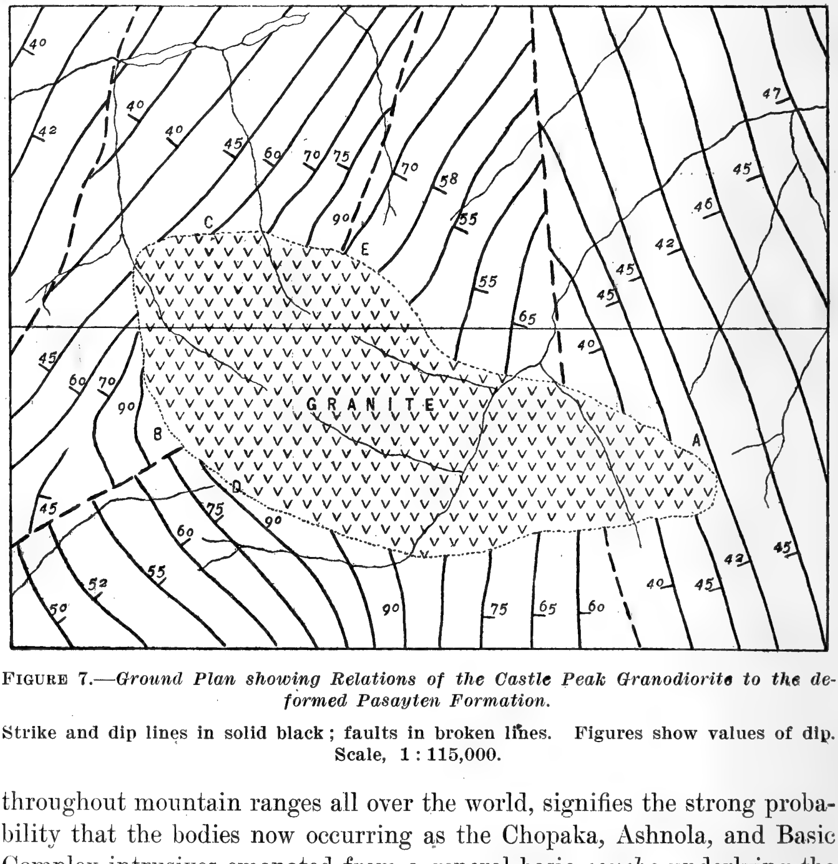

FIGURE 7.—*Ground Plan showing Relations of the Castle Peak Granodiorite to the deformed Pasayten Formation.*

Strike and dip lines in solid black; faults in broken lines. Figures show values of dip. Scale, 1 : 115,000.

throughout mountain ranges all over the world, signifies the strong probability that the bodies now occurring as the Chopaka, Ashnola, and Basic Complex intrusives emanated from a general basic *couche* underlying the mountain range.

Excluding the Kruger Alkaline body, then, it is seen from the table and from the petrographical descriptions that both of the respectively consanguineous series belong to a still greater series forming one petrogenic cycle. In this cycle the law of increasing acidity and diminishing

density of the materials successively irrupted and crystallized is rigidly followed.

For a new reason, therefore, it is profitable to regard the many intrusive bodies as forming a single composite batholith. Favoring that concept, the chemical and physical nature of the unit masses, systematically variable as these are, and the general geological structure of the Okanagan Range alike command attention. To the petrographical systematist the inclusion of such rocks as peridotites and gabbros with nepheline syenites and malignites may be like classifying bats with birds, but the geological and even genetic connection of both alkaline and non-alkaline types is here manifest.

Nature of batholithic Intrusions

REPLACEMENT THEORY AND ILLUSTRATION

Year by year the conviction has been growing ever stronger in the minds of many able geologists that such a batholith as any one of those here described has assumed its present size and position by actually replacing an equal or approximately equal mass of the older solid rock. The Okanagan Composite batholith repeatedly illustrates this truth. The writer is frankly unable to conceive that the huge Cathedral batholith, for example, could have been formed by any process of simple injection without leaving abundant traces of prodigious rending and general disorder in the

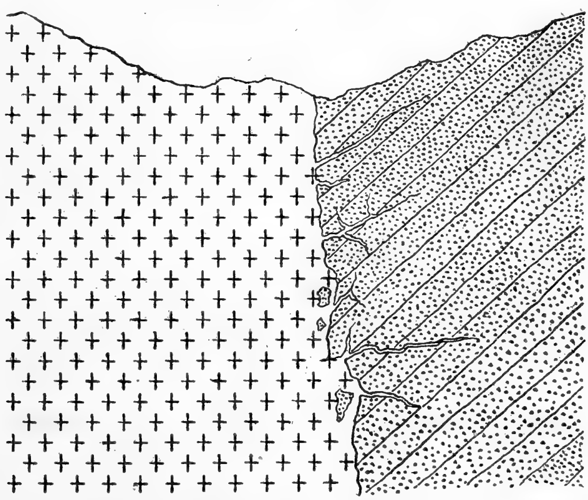

FIGURE 8.—*Contact Surface between the Castle Peak Granodiorite and tilted Cretaceous Sandstones and Argillites.*

The section is shown in the wall of a glacial cirque at the eastern end of the stock, the point marked "A" in figure 7. Scale, 1 inch to 175 feet.

granites alongside. We have seen, on the contrary, that the Similkameen granite on the east is notably free from such records of orogenic turmoil, while the shear zones of the Remmel batholith on the west most probably antedate the Cathedral granite intrusion. The very scale of these great bodies is suggestive of bodily replacement; it is hard to visualize an earth's crust which would so part as to permit of the laccolithic or chonolithic injection of a mass as great as a batholith.

The general absence of bedded rocks into which any one of the batholiths was irrupted means that some of the usual criteria of replacement can not be applied. It is therefore a matter of special importance that a

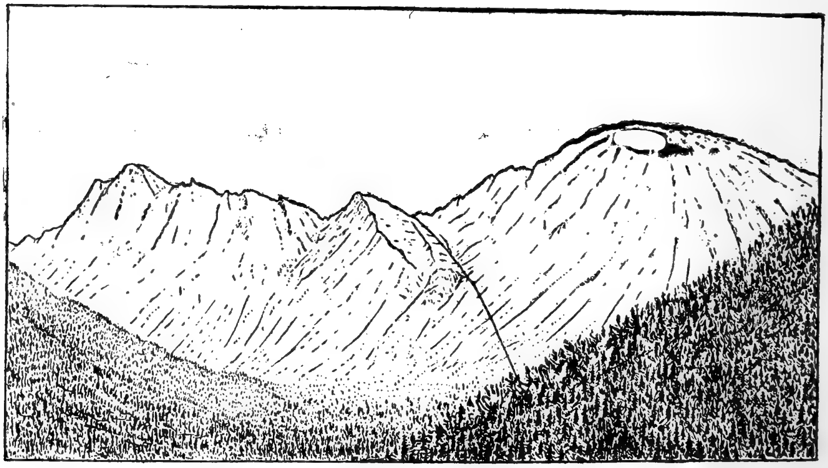

FIGURE 9.—*Plunging Contact Surface between intrusive Granodiorite and Cretaceous Argillites and Sandstones.*

Drawn from a photograph of the west end of the Castle Peak stock. View looks south. Contact shown by heavy line in middle of view; the point "B" in figure 7 is at the upper end of this line. Intrusive granodiorite on left, argillites and sandstone on right. The vertical distance between the two ends of the contact line as drawn is 1,500 feet. Castle peak on the left.

small Tertiary stock, such as Castle peak, a satellite of the composite batholith itself, gives unequivocal proof of the doctrine of batholithic replacement.

The Castle Peak stock, which covers 10 square miles in area, is located on the divide between the Pasayten and Skagit rivers, in the rugged crest of the Hozomeen division of the Cascade range. The peak is the highest of a group of noble mountains lying wholly or in part within this small plutonic area. This igneous body is composed of typical granodiorite with a strong basified contact zone of hornblende-biotite quartz diorite. The area and ground plan of the stock are shown in figure 7. The

country rocks are Cretaceous argillites and sandstones, so folded and faulted as to present dips varying from 40 to 90 degrees. Lines of strike and characteristic dips are illustrated in the diagrammatic map.

It can be seen from the map that the stock is not in laccolithic relations; but only in the field, as one follows the wonderfully exposed contact

FIGURE 10.—*Plunging Contact Surface between intrusive Granodiorite (on the right) and Cretaceous Formation (on the left).*

Drawn from a photograph taken on the north side of the Castle Peak stock, near the point "C," figure 7. View looking east. Contact shown by heavy line in middle of view. Granodiorite on right and Cretaceous formation on left. The vertical distance between the two ends of the contact line as drawn is 1,700 feet; contact also located in the background with broken lines.

line, does one appreciate the fullness of the evidence that the plutonic mass is a cross-cutting body in every sense. Even where the contact line locally coincides in direction with the strike of the sediments, as at the eastern end of the stock, the dipping strata are sharply truncated by the

granodiorite (figure 8). Moreover, the granodiorite was not introduced by any system of cross-faults or peripheral faults dislocating the sedimentary rocks. Owing to the special attitudes of the latter, the strike and dip of the beds would be peculiarly sensitive to such dislocation. The faulting actually displayed in the Cretaceous beds is strike faulting and was completed before the granodiorite was intruded (figure 7). The igneous

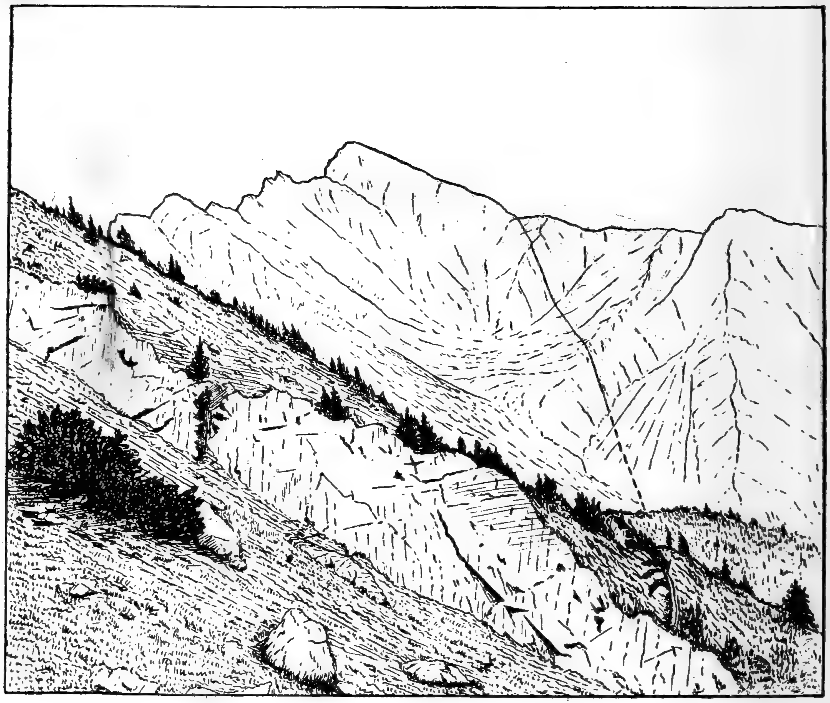

FIGURE 11.—*Plunging Contact Surface between intrusive Granodiorite and Cretaceous Formation.*

Drawn from a photograph taken on the south side of the Castle Peak stock, near the point "D," figure 7. View looking east. Contact shown by heavy line, right center of view. Granodiorite on left, Cretaceous formation on right. The vertical distance between the two ends of the contact line as drawn is 800 feet. The highest summit is Castle peak.

body is thus neither a bysmalith nor a chonolith. The magma entered the tilted sediments, quietly replacing cubic mile after cubic mile until its energies failed and it froze *in situ*.

Not only so; the superb exposures seen at many points in the deep canyons trenching the granodiorite illustrate with quite spectacular effect the downward enlargement of the intrusive body. At both ends and on both sides of the granodiorite body the steep mountain cliffs exhibit the intru-

sive contact surface through vertical depths of from 300 to 2,200 feet. In every case the contact surface dips away from the granodiorite, plunging under sandstone or argillite and truncating the beds. The angle of this dip varies from less than 20 degrees to 80 or 85 degrees (figures 9, 10, 11, and 12). On the north side of the granodiorite a section of the domed roof of the magma chamber still remains (figure 12). It is noteworthy that a well developed system of rifts or master joints in the granodiorite seems, with its low dip, to be arranged parallel to the north sloping roof, as if due to the contraction of the igneous rock on losing heat upward by conduction.

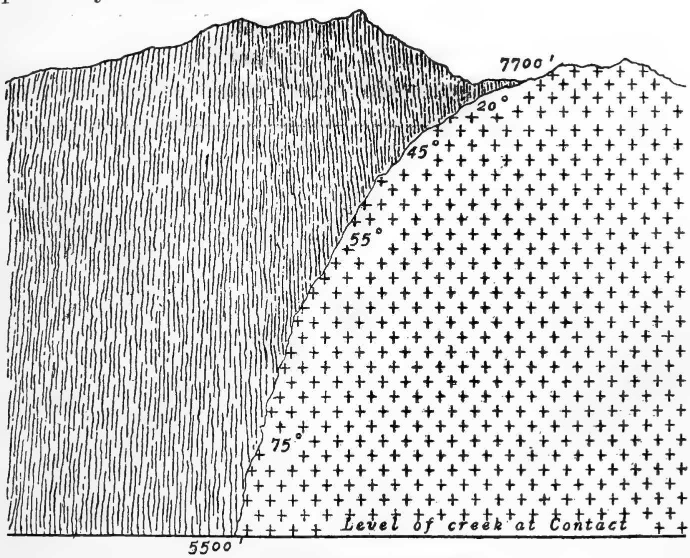

Figure 12.—*Intrusive Contact between Granodiorite and nearly vertical Cretaceous Argillites.*

Sketched in the field, on the north side of the Castle Peak stock, and seen in the wall of a deep canyon near the point "E," figure 7. Granodiorite on right and argillites on left.

This fact of downward enlargement makes it still more surely impossible to conceive that the granodiorite was injected into the sediments by filling a cavity opened by orogenic energy. A visible section even 2,200 feet deep does not prove the continuance of downward enlargement with depth; yet there is no logical reason to doubt that at least the steeper observed dips of the igneous contact surface are but samples of its dips for several miles beneath the present land surface. Moreover, if the granodiorite made its own way through the stratified rocks and was not an injected body, passively yielding to ordinary orogenic pressures, there must have been free communication between the now visible upper part of the

magma chamber and the hot interior of the earth. Downward enlargement is not only proved in visible cliff sections; it is demanded as a necessary condition of heat supply during spontaneous intrusion.

The Castle Peak plutonic body thus appears to be a typical stock, an intrusive mass (*a*) without a true floor, (*b*) downwardly broadening in cross-section, and (*c*) intruded in the form of fluid magma, actively, though gradually, replacing the sedimentary rocks with its own substance. It is the most ideally exposed stock of which the writer has any record.

BATHOLITHIC INTRUSION BY MAGMATIC REPLACEMENT

Without needing to revert to the accordant discoveries of masters in geology—of Suess, Barrois, Michel Lévy, Lacroix, Lawson, Dawson, and many others—we have here, within the Cascade mountains themselves,

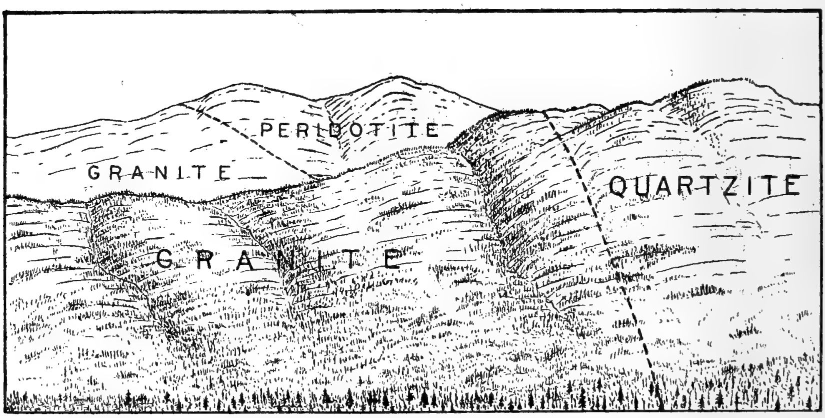

FIGURE 13.—*Plunging intrusive Contact Surface between the Similkameen Granite and the Chopaka Roof Pendant.*

Contact shown in broken lines. The vertical distance between the two ends of the contact seen on nearer ridge is 1,600 feet. Drawn from a photograph. Looking east.

illustrations of magmatic replacement. These authors believe, further, that a stock like Castle peak is but a small batholith; that several associated stocks may be in truth but protuberant parts of one subcrustal plutonic mass, which with further unroofing would declare itself a typical batholith. These views are consistently upheld by every pertinent structural detail that has yet been made out in the units of the composite batholith. Where bedded rocks still remain, they are cross-cut by the granitic bodies. Excellent exposures show that the contact surfaces of the Similkameen granite with the Chopaka Mountain and Snowy Mountain schist pendants dip underneath the invaded rocks, proving with every exposure seen the downward enlargement of the batholith (figures 13 and 14). In

one section more than half a mile in length the granite can be seen actually underlying a large section of the Snowy Mountain pendant.

In short, the fact of magmatic replacement and the related fact of downward enlargement of the great magma chambers seem to be well established. So fundamental are these facts that their evidence has been presented somewhat at length and with considerable illustration.

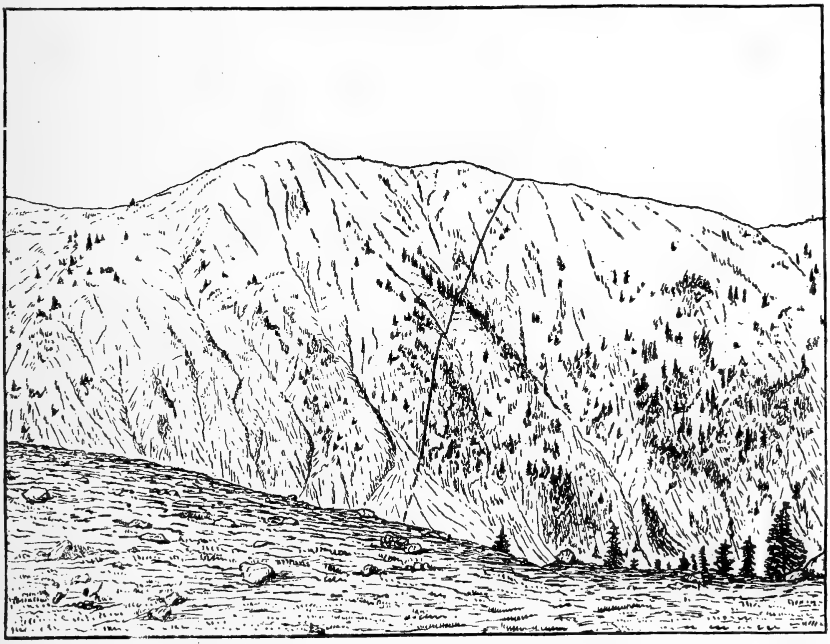

FIGURE 14.—*Outcrop of the intrusive Contact Surface shown in Figure* 13.
The vertical distance between the two ends of the contact line as drawn is 1,100 feet. The granite is on the right; quartzite and schist on the left. Drawn from a photograph. Looking west.

METHODS OF MAGMATIC REPLACEMENT; THE ASSIMILATION-DIFFERENTIATION THEORY

The chief petrologic problem consists in discovering the essential processes engaged in the magmatic replacement. In several publications the writer has treated of the various solutions of the problem.* On account of their complexity, the data for the best solution, attributing the replacement of the invaded formation to magmatic assimilation, may not here be stated in full. A very brief outline must suffice. Magmatic assimilation is regarded as of a double sort, consisting, first, of the pro-

*American Journal of Science, vol. 15, 1903, p. 269; vol. 16, 1903, p. 107; vol. 20, 1905, p. 185.

gressive fusion of main contact walls by original hot magma aided by its water and other solvents; secondly, of the progressive stoping of blocks (xenoliths) from the roof and walls of the batholith or stock, followed by the abyssal solution of the xenoliths in the hot interior of the magmatic body. Systematic differentiation of this new, widely extended, subcrustal, compound magma accompanies and follows the assimilation. The principal cause of differentiation has been sought in gravitative adjustment stratifying the magmatic *couche* according to the law of upwardly decreasing density (meaning, in general, increasing content of silica from below upward in the magmatic strata). A subordinate cause of differentiation commonly develops basified contact zones by the diffusion of basic materials to the surfaces of cooling. In the nature of the case, this latter kind of differentiation belongs to the late magmatic period immediately preceding crystallization; and, as illustrated in the Castle Peak stock and the Similkameen batholith, appears to form a basified zone along the roof as well as along the walls.

Partly for that reason it has proved impossible to discover a law of increasing density with depth in the Similkameen granite. A series of fifteen fresh specimens of the rock were collected at altitudes varying from 1,200 to 8,050 feet above sea, and their specific gravities were carefully determined. The difference between the densities of specimens taken near or at the two extremes of vertical distance was found too small to allow of a definite conclusion, though the difference, small as it is, favors the law of density stratification. It must be remembered, however, that the concentration of volatile matter, such as water vapor, dissolved in the magma but largely expelled during crystallization, would possibly be greatest at the roof. The specific gravities of the crystallized rocks may therefore not afford direct values for the total density stratification during the fluid state of the magma. Then, too, the observed relative uniformity of the Similkameen granite is a function of the scale of the subcrustal magma *couche*. It was unquestionably very thick; strong density differences are probably not on any hypothesis to be expected in a vertical section less than several miles in depth.

The objection has very often been made to the idea of extensive assimilation that signs of actual digestion about blocks broken off from roof or wall commonly fail. This is, however, just what would be expected on the stoping hypothesis. The very position of such a block shows that at the time when it was broken off it was floated in a magma too toughly viscous to allow the block either to rise or sink. Under those conditions the solvent or assimilative power of the magma is at or near its minimum. In other words, contact decrepitation persists some time after contact

fusion—the shatter period is longer than the fusion period. In a valuable paper on granites in New South Wales, Andrews has very clearly stated the case. Speaking of the New England batholiths, he says:

What we see are necessarily end reactions in the abyssal laboratories; for, however powerful the youthful stage of the invasion may have been, the present contact areas must represent the *dying struggles* only of the rising mass, since at these spots the intruding massif had no longer any *energy* left to replace the invaded rocks. Errors have often crept in, in the author's opinion, concerning the idea of rock assimilation through the lack of comprehension of this fact. For if weak, dying reactions give such results as one can see along the "blue granite" and later acid massif contact at Bolivia; along the Gympie slate and acid granite junction at Cow Flat; as also in the slates at Undercliffe, of what tremendous potency must such action have been possessed during its maximum strength, to wit, its youth or maturity.*

The reality of the shattering is abundantly, often dramatically, evident on most of the batholithic and stock contacts seen in the Boundary belt.

The leading question remains as to the nature of the original magma whose energies have effected the batholithic invasion. In the papers already cited the writer has shown reasons for believing that the initial magma in a complete petrogenic cycle is gabbroid, and thus basic in character. As so often pointed out by many authors, this magma is of such wide distribution that it seems to be original in the constitution of the earth. Its liquefaction, as with all plutonic magma, is doubtless consequent upon mountain-building disturbances. Given strong liquefaction, assimilation and batholithic intrusion automatically result.

It is clear that magma may be similarly formed by the abyssal fusion of sediments or schists through the rising of isogeotherms. That this of itself is not the explanation of most batholiths and stocks is disproved by the identity of material in contemporaneous bodies, though these respectively cut formations of quite different chemical composition. Simple fusion in place is also rendered improbable by the general sharpness of batholithic and stock contacts and by the manifestly exotic character of such a mass as the Castle Peak stock.

The original magma of the Okanagan Composite batholith may, as already noted, have been gabbro, now represented in the small intrusive (injected?) bodies occurring in the roof pendants. The Osoyoos and Remmel granodiorites resulted from the assimilation of Paleozoic and other old, relatively acid formations by the original magma. The Similkameen batholith must also include material won from the older grano-

*E. C. Andrews: The geology of the New England plateau, etc., Records Geological Survey N. S. Wales, 1905, vol. 8, p. 19.

diorites; and the Cathedral batholith, with its satellites, is a still later product, assimilating all the earlier formations, including possibly Cretaceous arkoses. Special differentiation at various times produced the Kruger Alkaline body and some of the dikes cutting the batholiths. In each irruptive epoch the crush of mountain building may have facilitated the liquefaction of the deeper lying portions of the invaded formations. Whatever the source of the heat, it was each time present in sufficient quantity to enable the magma of that stage to stope and dissolve its way upward, well into formations that were *not* fused through orogenic crushing. To that extent the magmas were superheated.

The assimilation-differentiation theory thus explains the sequence of the irruptions forming the Composite batholith. At each intrusive stage the magma set free to eat its way upward was more basic than the average of the rock invaded. At each stage a new magma, the one actually in contact with the invaded formations, was generated through absorption and gravitative differentiation, and the silica of the new magma was higher than that of the preceding batholithic magma. The increasing acidity is a function of the density, which decreases from below upward in the subcrustal magma *couche*. This law of density is preserved in the specific gravities of the batholithic rocks as now crystallized.

SKELETON HISTORY OF A BATHOLITHIC MAGMA

The development of any one of the batholiths may be summarized as follows:

1. A period of high liquidity, conditioned by orogenic movement. This period is characterized by—

a. Contact fusion;

b. Stoping and abyssal assimilation of xenoliths, progressive modification (here acidification) of magma;

c. Injection of wide ranging apophyses;

d. Gravitative differentiation of the compound magma of assimilation;

e. Possibly the beginning of basic segregation.

2. A period of strong and increasing viscosity—a period characterized by—

a. Cessation of magmatic digestion;

b. Some subsequent continuation of contact shattering;

c. Completion of the observed segregation of basic materials in nodules and contact zones; development of maximum acidity in the main body of the batholith;

d. Crystallization of the mass during a viscous condition approaching that of a solid solution.*

General Summary

1. At the 49th parallel of latitude the Okanagan mountains and a part of the belt of the Interior plateaus (the Interior plateau of Dawson) have been carved by erosion out of an assemblage of plutonic igneous rocks which, in spite of the diverse lithological character of the rocks, should be regarded as an enormous single member of the Cordilleran structure. This plutonic group is named the Okanagan Composite batholith. The details of its constitution are given in a foregoing résumé of its geological history.

2. This composite batholith was of slow development, beginning with small intrusions in late Paleozoic (or possibly Triassic) time, increased by great batholithic irruptions of granodiorite during the Jurassic, and completed by likewise immense irruptions of alkaline hornblende-biotite granite and biotite granite—batholiths of Tertiary age, possibly as late as the Upper Miocene or the Pliocene. The satellitic Tertiary stock of Castle peak in the Hozomeen range, is composed of normal granodiorite.

3. The local intrusion of a small, composite body of malignites and nepheline syenites; the regular basification along the batholith and stock contacts, giving collars of monzonites and diorites; and the sporadic appearance of certain peridotites (hornblendites and dunites) are probably all incidents of magmatic differentiation and do not directly represent the compositions of general subcrustal magmas.

4. The composite batholith and the Castle Peak stock offer striking testimony to the probable truth of the assimilation-differentiation theory of granitic rocks. A very brief summary of this theory is given above in the form of a skeleton key to the history of a batholithic magma.

5. The composite batholith includes two consanguineous series of intrusions. The older one is non-alkaline; the younger, alkaline. They are separated in time by the whole Cretaceous period, at least.

6. The two consanguineous series nevertheless appear to belong to one petrogenic cycle. Throughout the cycle batholithic intrusion has followed the usual law of decrease in magmatic density and increase of magmatic acidity with the progress of time.

7. Exposures of contact surfaces in the Castle Peak stock and in the Similkameen batholith illustrate with remarkable clearness the downward enlargement of such bodies with depth.

*Cf. Brauns, Chemische Mineralogie. Leipzig, 1896, p. 97.

8. The Similkameen granite bears three roof pendants. Their distribution suggests that the present erosion surface of this batholith west of the Similkameen river is not far from coinciding with the constructional, subterranean surface of the batholith.

9. The Osoyoos and Remmel granodiorites have been extensively metamorphosed by orogenic crushing and its attendant processes. The metamorphism was both dynamic and hydrothermal. The granodiorites have been locally, though on a large scale, transformed into banded gneisses and schists. These changes have been brought about through the hydrous solution and migration of the original mineral substance of the granodiorites, especially the more basic minerals. The dissolved material has been leached out from the granulated rock and has recrystallized in strong shear zones to which the solutions have slowly traveled. The shearing and metamorphism probably began at a time when the Remmel batholith was buried beneath at least 30,000 feet of Cretaceous strata.

10. The intensity of this metamorphism and the development of the great Tertiary batholiths agree with other facts to show that post-Jurassic mountain building at the 49th parallel was caused by much more powerful compression than that which is shown in the broader Cordilleran zone passing through California; there the Jurassic batholiths are relatively uncrushed and Tertiary batholiths seem to be lacking.

11. The problems of the Okanagan Composite batholith illustrate once again, and on a large scale, the utmost dependence of a sound petrology upon structural geology. A suggested chief problem involves the relation of mountain-building to the repeated development of large bodies of superheated magma only a few miles beneath the surface of the mountain range. The fact of this association is apparent; its explanation is not here attempted.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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OBSERVATIONS IN SOUTH AFRICA

BY W. M. DAVIS

(Read before the Society December 28, 1905)

CONTENTS

Introduction

THE JOURNEY

During the summer of 1905 I had the good fortune, as one of the foreign guests, to accompany the party of the British Association for the Advancement of Science on a visit to the colonies of South Africa. The chief dates of the journey were as follows: Having left New York on July 15, I sailed from Southampton on the steamer *Saxon* with the third detachment of the Association party on July 29, and reached Cape Town on August 15. Meetings were held there for three days. On August 19 I set out by rail (see figure 1) with a party of geologists for the interior, spent four days in the Karroo, and then hurried across country via Johannesburg to join another geological party in the Vryheit district of Natal. Returning to Johannesburg, meetings were resumed from August 29 to 31, and then a third geological excursion was made to the Duivels Kantoor, on the escarpment of the highland, east-northeast of Pretoria, September 2 to 4. We again came back to Johannesburg, whence a long southward detour by rail took us to Kimberley, where the main party was overtaken. After a day there, September 6, we started northward in special trains for Bulawayo, where we spent September 9 and 10, including an excursion to the granite hills, or Matopos, on the second day; and on September 11 set out for the Victoria falls of the

Zambesi, our farthest inland point, arriving there the next morning and starting back the following day, September 13. We reached Bulawayo again on September 14. Here the party divided, some going southward to Cape Town and thence to England by direct steamer, while others, including the writer, went eastward for a longer journey. We reached Salisbury, the capital of Rhodesia, on September 15; Umtali, on September 16, and Beira, in Portuguese East Africa, on September 17. There the homeward journey was begun in the steamer *Durham Castle,* which had been especially chartered to return by the east coast of Africa, the Suez canal, and the Mediterranean. Marseilles was reached on October

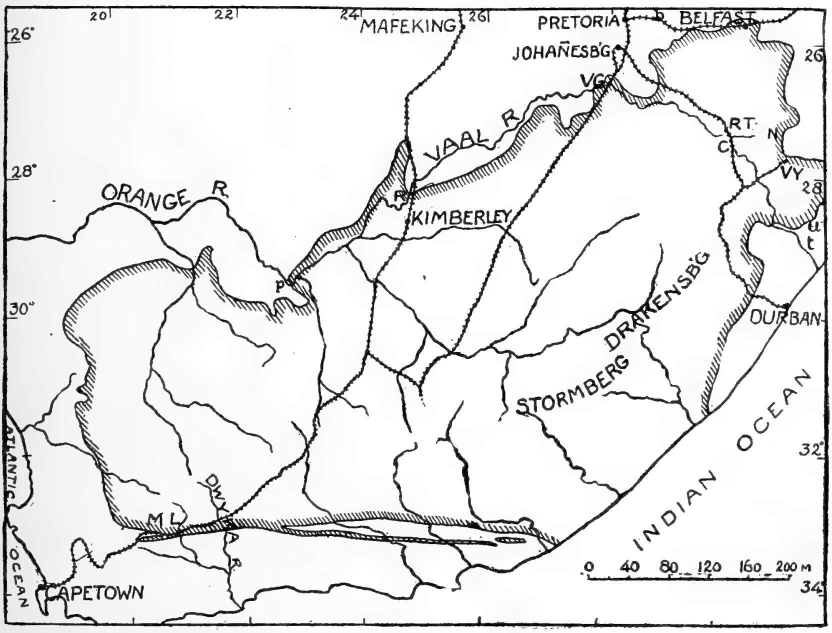

FIGURE 1.—*Outline Map of Area occupied by the Dwyka glacial Formation.*

The margin of the formation is cross-lined. The localities indicated by initial letters are as follows: C, Charlestown, Natal; L, Laingsburg, Cape Colony; M, Matjesfontein, Cape Colony; N, Ngotsche, Natal; R, Riverton, Cape Colony; RT, Volksrust, Transvaal; VG, Vereeniging, Transvaal; VY, Vryheit, Natal; *b*, Balmoral, Transvaal; *p*, Prieska, Cape Colony; *u* and *t*, on the Umfolosi and Tugela rivers, Natal.

17, and at Liverpool, October 24, began the homeward Atlantic voyage, from which I landed in Boston November 2, after an absence of 110 days, of which 58 had been spent at sea and 33 in South Africa. An extraordinary feature of the journey, highly indicative of its careful planning and excellent management, was that all the arrivals and de-

partures in South Africa were effected on the days, practically on the hours, that had been planned and published before the oversea party had left England.

PHYSIOGRAPHIC DIVISIONS OF SOUTH AFRICA

The greater part of the region that we traversed is included in the extensive highland or high-standing peneplain, with an altitude of from 4,000 to 6,000 feet, which forms the body of the South African interior. Over the greater part of this region, 1,000,000 or more square miles in extent, there has been no strong deformation for many geological ages, although Passarge (page 596) states that there are some Mesozoic graben in the Kalahari region. The southern part of the highland region has been still quieter, for if the slow and gentle depression by which the Karroo basin of heavy Mesozoic deposition was formed be neglected, as it may well be because of its equable nature, there has been no considerable deformation since pre-Devonian times. Much of this district is commonly spoken of as the "Veld" (pronounced felt); its higher parts are the High Veld. It is characteristically treeless over large areas, but in the north, where tree-growth occurs, it is called the Bush Veld. Its wet season is the summer of the southern hemisphere, when a rainfall of about 30 inches is recorded, much of it falling in heavy, short-lived showers, and causing sheetfloods on the unchanneled slopes and rapid changes of volume in the rivers. As the time of our visit fell near the end of the winter season, the Veld was dry and brown when we crossed it.

A number of subparallel mountain ridges, trending east and west, occupy a belt of country some 60 or 80 miles in width across the southern end of the continent. These are built chiefly of Paleozoic formations that were crushed into folds in Mesozoic time and afterward greatly eroded. In the absence of other general name, they will be here called the Cape Colony ranges. Associated with the east and west ridges are others of smaller dimensions, trending north and south, one group in the southwest corner of the continent and another of less pronounced relief along the eastern coast in Natal. The southern part of this mountainous belt, near the coast, lies in the subtropical belt of the southern hemisphere, and receives its rainfall chiefly in the southern winter season, when the cyclonic areas of the prevailing westerly winds have a more northerly path than in the other half of the year; but they seldom reach the inner part of the mountainous belt, known as the Karroo, which is therefore dry all the year round. The highest of the east and west ridges, which reach altitudes of some 6,000 feet, aid in determining a dry

climate for the next inland lowlands of erosion. The broadest of these is known as the Great Karroo, and lies between the northernmost mountain ridge and the south-facing escarpment of the interior highland, while a similarly arid belt between two of the chief mountain ridges is called the Little Karroo. In distinction to these lower areas, the highland of the Veld, next north, is sometimes called the Upper Karroo.

The descent of the interior highland on the east to the coast of the Indian ocean is relatively rapid. Here the rainfall from the impinging trade winds is more plentiful and vegetation is more luxuriant. The streams of this slope have a pronounced gradient and are actively encroaching on the headwaters of the Orange River system by which the highland is drained to the Atlantic. The western side of the highland is more arid and includes the desert of Kalahari, of which we saw only the eastern margin on our northward journey.

PROBLEMS HERE CONSIDERED

The opportunity for geological and geographical study during a land journey of only 33 days, during which a distance of about 2,500 miles was traversed by rail, was distinctly limited. Nevertheless, by taking advantage of as many geological excursions as possible and by devoting close attention to the study of the landscape during the train journeys, much profit was derived, no small share of which came from the very advantageous conferences with South African and European members of the party. The chief subjects here presented are: The Cape Colony ranges, considered with special regard to their resemblance to the Allegheny mountains of Pennsylvania and Virginia; the Dwyka (Permian) glacial formation, or tillite, to which more attention was given on the ground than to any other problem; and the peneplain of the Veld or interior highland and the conditions of its origin. Briefer discussion is made of the origin of the zigzag gorge below the Victoria falls of the Zambesi, in which the explanation offered by Molyneux is accepted, and of several general problems, such as the continental origin of the Karroo and other formations; the homology of the Karroo Mesozoic basin with the Tarim basin of central Asia, the probability of the former greater extension of Africa to the east, south, and west, and the dissimilarity of South Africa and southern South America.

ACKNOWLEDGMENTS

Special acknowledgment of assistance is due to all the South African geologists who gave us the aid of their experience on the various excur-

sions, and more particularly to Mr Arthur W. Rogers, geologist of Cape Colony; Mr William Anderson, geologist of Natal; Dr G. A. F. Molengraaff, formerly geologist of the South African Republic, and Dr F. H. Hatch, president of the Geological Society of South Africa. Our indebtedness to the first and last named of these accomplished investigators is the greater because of their service in the preparation of admirable handbooks on the geology of South Africa, recently published. From first to last, the generous policy of the British Association, which enabled its foreign guests to take part in the great excursion, awakened our liveliest gratitude.

The Cape Colony Ranges

LOCATION AND STRUCTURE

The southern border of Africa, for a width of from 60 to 80 miles, is a mountainous tract of subparallel ranges extending east and west with much regularity. Singularly enough there appears to be no general designation in common use for this system of mountains as a whole, and I shall here refer to them under the convenient name given above. They are intimately associated, as has already been pointed out, with ranges of less extent running north and south in the southwestern corner of the continent, and they appear to be genetically associated, although not visibly connected with other north and south ridges of less pronounced deformation and relief along the east coast in Natal. The angle where the southern ranges and those of Natal would meet (see figure 1) lies in the Indian ocean, whose shoreline passes obliquely northeast across the series of east-west ranges, the Mesozoic basin of horizontal strata, and the series of north-south ranges in the most unconformable fashion, highly suggestive of the truncation of the continent by deformations which have brought the ocean against a new coastline, as will be more fully considered in a later section.

The strata involved in the Cape Colony ranges are mostly of Paleozoic age, and were originally spread out in great sheets of considerable uniformity horizontally, but of marked diversity vertically. They constitute the Cape system and the Karroo system. The first system includes the heavy Table Mountain sandstones, 4,000 or 5,000 feet thick; the Bokkeveld (goat pasture) shales and sandstones, containing marine Devonian fossils, about 2,500 feet thick, and the Witteberg series, chiefly sandstones and quartzites, 2,500 feet thick, or 10,000 feet in all. The Karroo system begins with the extraordinary Dwyka glacial formation, 1,000 feet in thickness, after which come the Ecca, Beaufort, and Stormberg

series of shales and sandstones, all of continental origin and including many dikes and sheets of dolerite. The Ecca and Stormberg series contain coal; the Beaufort series is famous for its reptiles.

The floor on which the Cape system rests consists of the Malmesbury slates, regarded as Archean, with intrusive granites, well exposed along the shore at Sea Point, a western suburb of Cape Town, where several of the geologists of our party saw them in an interesting excursion under the guidance of Mr Dutoit, of the Cape Colony Geological Survey. These older rocks were reduced to an essentially plane surface, in the Cape Town district at least, before the deposition of the Cape system, as is proved by the even surface of contact between the two around the northern escarpment of Table mountain. A peculiar feature of the Cape system is the absence of marine fossils, except in its middle member; it has therefore been suggested that the Table Mountain and the Witteberg sandstones are of continental origin, and that they resemble in this respect the formations of the overlying Karroo system, for which a fuller statement will be made in a later section.

The following table summarizes the succession of the formations involved. It should be noted that the strata of the Karroo system occupy a large part of the interior highland, or Veld, and therefore far outrun the area of the Karroo district from which their name was taken:

Karroo system, 20,000 feet.	Stormberg	Sandstones and shales.
	Beaufort	
	Ecca	
	Dwyka tillite and shales.	
Cape system, 10,000 feet.	Witteberg sandstones and shales.	
	Bokkeveld sandstones and shales.	
	Table Mountain sandstones.	

ANALOGY OF THE CAPE COLONY RANGES WITH THE ALLEGHENIES

The east and west ranges, of which the Zwartbergen and the Langebergen are the most conspicuous members, are of especial interest to American geologists because of their resemblance in several respects to the Allegheny mountains of Pennsylvania and Virginia, the middle section of the Appalachians. The heavy strata involved are in both cases chiefly of pre-Permian age. Forces of compression have in both the Alleghenies and the Cape Colony ranges crowded a great part of the area of the strata concerned into long subparallel folds, with overturns and overthrusts directed inland, but have left the farther interior area practically undisturbed, this area constituting the Allegheny plateau in one case and the highland of the Veld in the other. Hence it may be in-

ferred that the tangential thrust by which the compression and overturning were produced was in both cases directed from the region that is now ocean toward the region that is now land—from southeast to northwest in the eastern United States, from south to north in South Africa. This analogy suggests another, namely, that as the chief source of the sediments was on the ocean side of the present ranges in the Appalachians, where Paleozoic land is recognizable in the older crystalline belt, a similar relation may have obtained in South Africa; but this speculation is to a certain extent contradicted by the fact that the texture of some of the members of the folded series there increases in coarseness toward the west and northwest, as if the sediments had been derived from the ancient rocks north of the lower Orange river, 300 or 400 miles away from the ranges in question. However, there are in general so many examples of mountain-making deformation having invaded areas of heavy deposition—piedmont to the source of the deposited sediments—that it is tempting to inquire whether such may not have been the case with the South African ranges also; and in spite of the absence of any visible area of older rocks along the south coast from which the heavy Paleozoic sediments might have been derived, it remains possible that such a source may have lain somewhat farther south, and that it has since then disappeared by submergence. The suggested source of the strata of the Cape system north of the Orange river might in that case be compared to the partial source of the Appalachian sediments in the oldlands of northern Wisconsin, which is not at all inconsistent with their main source having been in the old Appalachian belt.

A vast amount of erosion has occurred in these mountain systems since they were folded, so that the existing longitudinal valleys and lowland belts are entirely due to erosion, and the linear ranges and ridges of today are merely the residual reliefs of the more resistant formations, without essential relation to belts of uplift. Thus the Little and the Great Karroo are nothing more than narrower and wider lowland belts that have been eroded along the strike of the less resistant formations between and north of the east and west ranges. They correspond closely in origin, though not at all in climate, to the similar lowland belts or valleys in the Appalachians. As a result of this heavy erosion, the formations of the Karroo system have been almost completely removed from the district of the Cape Colony ranges, but several significant patches of Dwyka and Ecca beds remain in synclines, and from this their former general southward extension must be inferred.

As to the occurrence of two or more cycles of erosion during the wearing down of the South African ranges, I did not see any striking exam-

ples of formerly baseleveled monoclinal ridge crests in South Africa comparable to the even crested monoclinal ridges of Pennsylvania; but the relation of the southern ranges to the peneplain of the interior highland made it seem very probable that in South Africa, as in Pennsylvania and Virginia, the erosion of the mountains has not been a continuous process with respect to a single baselevel, and that the Cape Colony ranges may well have been, like the Appalachians, once at least reduced to a much smaller relief than that of today, only to be brought into strength again as a result of revived dissection and etching out of the weaker beds, following renewed elevation. The drainage in both systems includes numerous subsequent rivers and valleys* which exhibit marked examples of adjustment of streams to structures rather than persistence in originally consequent courses. Whether the amount of adjustment is no greater than could have taken place in the continuous processes of a single cycle of erosion, or whether it is so great as to demand for the Cape Colony ranges the aid of a second cycle in which to supplement the work of a first cycle, as seems so clearly to have been the case in the Alleghanies, I can not venture to assert from the facts in hand; but the data presented by Schwarz (*a*) regarding the high-standing, gravel-covered planation surfaces or terraces among the ranges and the strong evidence of peneplanation in the Veld make more than one cycle of erosion of the mountain belt extremely probable.

DRAINAGE PROBLEMS

The numerous narrow and deep-cut water gaps in the ridges, through which the open longitudinal valleys are drained, afford remarkably fine instances of the manner in which a belt of resistant rocks may long maintain the narrow form of a young valley, while the belts of weaker rocks, upstream and downstream from the gaps, permit their valleys to be carried forward to the stage of maturity or even to that of old age. The suggestion that the gaps are due to convulsions of nature, with the tacit postulate that the ridge in which the gap is opened and the open

*The term "subsequent" is here used consistently with the definition given to it in 1889—see "The rivers and valleys of Pennsylvania," National Geographic Magazine, vol. i, 1889, p. 207—to designate rivers and valleys that have been developed by headward erosion along a belt of weak strata, and not to include all valleys of erosion, in contradistinction to original or tectonic valleys, as later suggested by J. Geikie in his book "Earth Sculpture," 1898, pp. 277-279. While the rule of priority is not recognized as binding in physiography, it seems regrettable that a term like subsequent, the use of which in a certain limited sense has been clearly set forth, should afterward be used in a much more general sense, particularly when no indication of the change of meaning is given to the reader.

low country on either side of it are of earlier origin than the gap, seems to be indigenous in South Africa as it is in Pennsylvania, thus adding still another feature of similarity—a geographical habit of mind—between the two regions. The more rational explanation of all such gaps as of the same age as the open low country, when measured in years, though of very different stage of development when measured by the physiographic scale, is slow to find popular acceptance.

The general drainage system to which the rivers of the deep-cut water gaps belong is peculiar in that its members head on the inland side of the Cape Colony ranges and maintain generally transverse courses southward to the ocean. The river heads are in most instances on the Veld itself, 60 or 80 miles north of its south-facing escarpment, and flow from the highland in valleys by which the escarpment is much dissected. All this is noteworthy because it involves the drainage of a relatively undisturbed area—the southern part of the Veld—by rivers that cross a broad belt of strongly disturbed and upfolded strata in the Cape Colony ranges. It is all the more noteworthy because it constitutes still another feature of systematic resemblance with the Appalachians of Pennsylvania and Virginia, where the Delaware, Susquehanna, and Potomac exhibit essentially the same peculiar relations to the areas of horizontal and folded rocks.

An origin for the South African drainage system has lately been suggested by Schwarz (*b*). This writer points out the remarkable directness of the watershed between the Orange River system and the Indian Ocean drainage, from Cape Town to Delagoa bay, and then adds:

> I can not conceive of any explanation for such an arrangement except that which assumes that there was a vast plain stretching over the whole land when the subcontinent first rose from the water's edge, and that the central ridge [the watershed] was already then formed. If we examine the central parting of the waters, we find that there is no structural cause for its existence; there is no backbone of igneous rock, nor is there a chain of folded mountains to account for it; neither, again, is there a wide anticlinal arch, for the beds dip in toward it. I have adduced reasons elsewhere for supposing that the watershed owes its origin to the manner in which the Karroo sediments were laid down; they were accumulated on [in ?] the thickest deposits about 150 miles from the old Permian shoreline, which ran northeastward to the north of the watershed. When elevation began, the curvature of the basin in which they were lying was reduced, and consequently the thickest deposits formed an elevation, which at once became a water-parting.
>
> This original plain was about on a level with the main watershed as it exists today, for I have seen evidence elsewhere of the extremely little erosion that takes place on a flat water-parting, and roughly we can say it is so now at an elevation of 6,000 feet above sealevel.

It is perhaps somewhat inappropriate for one who has only made a flying trip across a large region not to accept the conclusions of another who has gained a close acquaintance with it by long residence and numerous journeys; nevertheless I am constrained to differ in many ways from the theoretical statements made in the above citation. In the first place, the directness of the "main watershed," which is shown as a straight line on the map in Professor Schwarz's paper, appears to me simply as one of those many examples of accidental coincidence of which the world is full, and hence of the same order as that class of coincidences noted when the rectilinear prolongation of a fault line, determined by geological evidence in one district, leads to a river course, mapped in an adjacent district without any evidence of its being related to faulting. Such a coincidence may be determined by a causal relation, and it may not. The directness of the main South African watershed on which Schwarz lays much emphasis is, however, more imaginary than real, for it is drawn as a direct line only by making the unwarranted assumption that the present head of the Orange river in the Stormbergen and Drakensbergen of Basutoland, which is about 150 miles southeast of the direct line, is a later extension of the original head beyond the assumed main or direct watershed. It might be suggested with greater probability of correctness, it seems to me, that the original head of Orange river lay even farther southeast of the so-called "main watershed" than the present head does, and thus departed even more from the direct line then than it does now; the evidence for this view being found in the peculiar truncation of the geological structures along the Cape Colony-Natal coastline, already alluded to, and illustrated in figure 1. Furthermore, the main watershed as drawn by Schwarz follows divides that must be of very different origins and of very different dates of development; it is therefore a line that brings together incongruous elements and treats them as if they were congruous. This may be seen by a review of its several parts. At its beginning near Cape Town it runs between the opposing and competing headwaters of rivers that drain longitudinal valleys between the folded mountains, and whose present separation can not reasonably be taken as still closely accordant with the initial divide when the subcontinent first rose from the sea. The present divide is the result of long competition by rival streams, as later pages (274 *et seq.*) of Schwarz's paper clearly show. At the other end of the line, near Delagoa bay, the divide is drawn obliquely between two east-flowing streams by which the escarpment of the interior plateau is drained to the Indian ocean; and these streams must be of much later origin than the first elevation of the continent, for they are evidently related to that modern displacement

whereby the southern, southeastern, and eastern coastline was determined, as will be more fully set forth further on.

But the most serious objection that I feel against Schwarz's explanation of the great antiquity and long persistence of the straight "main watershed" is that such an explanation entirely overlooks the changes that must reasonably be expected to have taken place by the interaction of the rivers themselves during the long periods of erosion to which the region has been subjected since middle Mesozoic time. The great diversity of structure and the well proved changes of level in the region during its continental existence, probably involving two important cycles of erosion at least, must have contributed effectively to the changes of drainage area that the competing rivers would have themselves brought about. Such changes are today in active progress at the head of the Vaal river and its branches, where the shorter and steeper east-flowing streams are gaining area at the expense of the longer west-flowing rivers, as will be more fully set forth in the section concerning the eastern escarpment. To take no account of all these possible changes, and therefore to regard the existing watershed as having persisted through geological ages, involves probable errors of the same order as those which were introduced in the interpretation of our Cordilleran physiography thirty years ago by the wholesale suggestion of an antecedent origin for many rivers, small as well as large, in Utah and Arizona.

The extensive rearrangement of initial drainage lines in a long eroded region, partly through the development of subsequent rivers by headward erosion along belts of weak strata, partly through the encouragement of headward erosion given to rivers of all classes by favoring crustal deformation, is now too well established a procedure in the general natural history of rivers to be set aside, unless by the strongest positive evidence in particular cases. In the absence of such evidence, it may be safely concluded that the existing transverse drainage of the Cape Colony ranges, like the comparable transverse drainage of the Appalachians, has come into existence at a date much more modern than that of the original elevation of the region above sealevel. Just how the transverse drainage came to be established it is difficult to determine with any certainty on existing information, but there is some reason for thinking that, in South Africa as in Pennsylvania and Virginia, it was not developed until during and after the general peneplanation of the Veld and the upfolded ranges, and that whatever drainage lines—already much changed from the initial lines—had come to exist on the peneplaned surface, the weak old streams of that time were profoundly affected by the broad warping and the general changes of level which resulted in the

establishment of the present relations of the interior highland to the continental coastline, and that still further changes were spontaneously introduced by the rivers themselves during the present cycle of erosion then initiated. This subject is pursued somewhat further in an article in a recent Bulletin of the American Geographical Society.

THE KLEIN ZWARTBERG AND THE WITTEBERGS

We had opportunity of seeing several of the Cape Colony ranges close at hand during the excursion in the Karroo with Mr Rogers, and it was of special interest to note that the east and west mountains were usually of anticlinal structure. The most striking example of this kind that came within our observation was the Klein Zwartberg, the western end of a long range of Table Mountain sandstones whose central and eastern part is known simply as the Zwartberg, 6,000 or 7,000 feet in height. This mountain was, to be sure, seen only at a distance of some 10 miles, but it presented a striking resemblance to some of the anticlinal mountains of Medina sandstone in Pennsylvania, even to the sharp-cut gap by which Buffels river escapes through it southward—a close match to the deep gap of the Juniata in Jacks mountain, central Pennsylvania. A notable feature of the South African view was the absence of verdure on the mountain slope. The whole surface seemed to be of bare gray sandstone, trenched by the gorges of short resequent streams, this being a strong contrast to the forest-covered ridges of Pennsylvania and Virginia. The effect of the Cape Colony ranges in walling off one lowland belt from another was very marked; for while they were by no means unsurmountable, a road over them would be difficult to construct and to maintain and as difficult to use; hence the great economic importance of the water gaps as roadways, already reduced to moderate grades by natural processes. The Buffels River notch through the Klein Zwartberg is shown in the background of figure 6.

The Witteberg ranges south of Matjesfontein and Laingsburg were seen to better advantage than the Zwartberg, for our route lay near the northern base of one of them for a number of miles and crossed another at two points. Their altitude is less than that of the heavier Table Mountain sandstone ranges. They everywhere showed strong deformation, with frequent overturns and overthrusts toward the north. The ridge next south of Matjesfontein (M, figure 1) fades away a few miles farther east, where its anticlinal axis pitches gently underground, so that its resistant sandstones and quartzites are succeeded in that direction by weaker sandstones and shales, chiefly the lower members of the overlying Karroo system. A second range then comes into view, some 5

miles farther south (plate 48, figure 2); it was this one we crossed in our second day's excursion from Laingsburg (L, figure 1), August 22, when we drove 20 miles southward down the valley of Buffels river, through its gorge (plate 47, figure 1), Leeuw Kloof poort, or Lion Ravine gap, in the Witteberg ridge, where good sections were abundantly exposed.

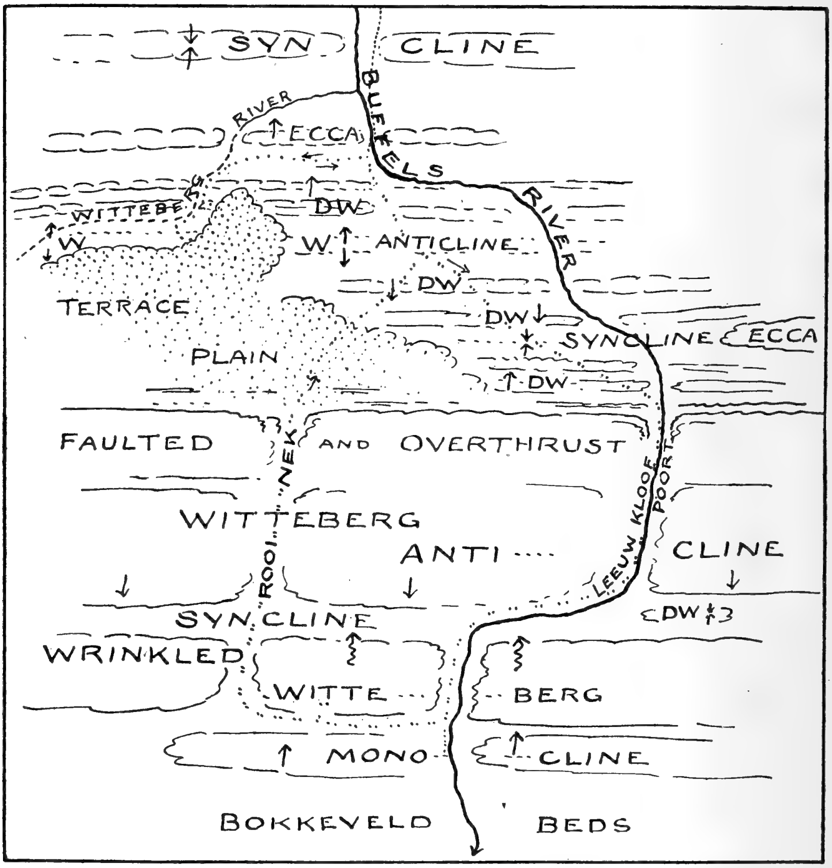

FIGURE 2.—*Sketch Map of District South of Laingsburg, Cape Colony.*

Shows gorge of the Buffels river through the Witteberg range. Scale, about five miles to an inch. Route of excursion on August 21, single dots; on August 22, double dots.

The general distribution of the ridges hereabout is roughly sketched in figure 2, on which our route is shown by a line of double dots. The section in the gorge, sketched as we drove through it, is reproduced in figure 3. The range appears to be a double or faulted anticline, with steep dips and overthrusts along its northern border, where the Witteberg

quartzites plunge underground. Farther northward they remain covered beneath the heavy Karroo formations. A view of the northern base of the mountain is given in plate 47, figure 2, showing vertical strata.

On recrossing the range, when returning by Rooi Nek pass about 10 miles farther west, the vertical dips were replaced by overturns, with strong suggestion of overthrusts. A narrow longitudinal synclinal valley

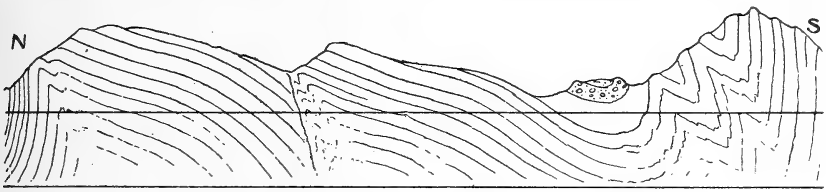

FIGURE 3.—*Rough Section of Witteberg Range, looking East.*

The locality is at gorge of Buffels river, south of Laingsburg, Cape Colony. Length, about 10 miles. A patch of Dwyka tillite remains in the synclinal valley.

south of the range held a patch of Dwyka tillite near the point where we entered it (see figures 2 and 3), thus proving the original extension of at least the Dwyka or basal member of the Karroo system southward into the region of strong folding. The extension of still higher members of the Karroo formations is indicated by the excessive plication which the Witteberg quartzites have suffered hereabout, for this implies that

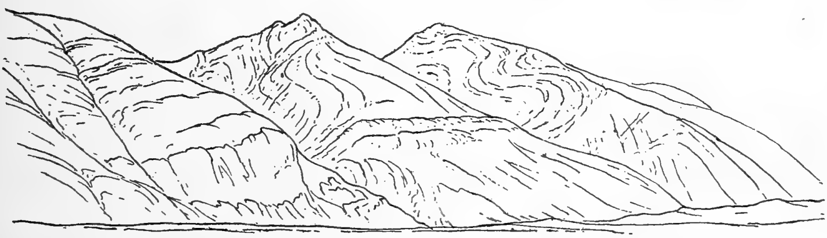

FIGURE 4.—*Northern Face of the southern Witteberg Ridge, looking Southwest.*

The foreground is a synclinal valley, followed for a few miles by Buffels river between its upper and lower notches.

they were buried under a heavy load at the time of their deformation. This is especially true of the ridge that rises next southward from the synclinal valley; it is a severely wrinkled monocline, where the Witteberg series rises into the air to vault over the great Zwartberg anticline still farther south. The Bokkeveld beds follow this ridge with many minor folds on which a rolling lowland or longitudinal valley has been opened. A view of the northern face of the wrinkled monocline, next east of the Buffels River notch, is given in figure 4, looking southwest; this was drawn close to the first L of "Leeuw Kloof poort," in figure 2.

A view of the same ridge, shown in natural section on the eastern side of the notch cut by Buffels river, is given in figure 5, looking northeast. This was drawn from a knob near the letters TT of "Wrinkled Witteberg" in figure 2, about 2 miles west of the notch. A notable feature of

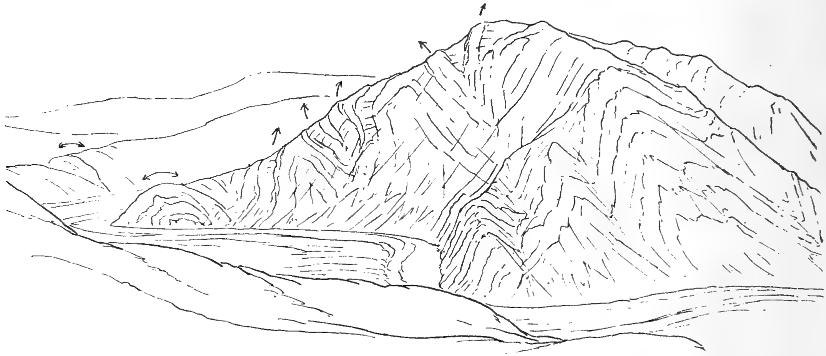

FIGURE 5.—*Eastern Wall of Buffels River Notch.*

The notch is in the southern Witteberg ridge, looking northeast. Three anticlines and three synclines are here seen, truncated by the northern slope of the ridge.

the view is the repetition of a certain band of whitish quartzitic sandstone in three anticlines and three synclines, across which the northern face of the ridge is indifferently beveled. The same band of sandstone is seen in a local ridge in the distance, where it rises north of the longi-

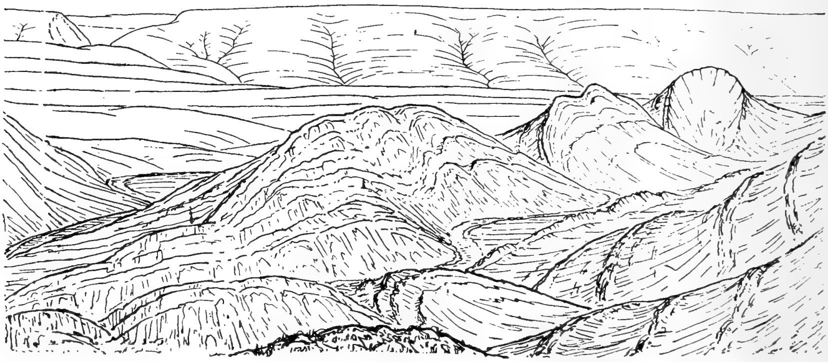

FIGURE 6.—*Southern Slope of the southern Witteberg Ridge.*

A lowland of Bokkeveld strata is in the middle distance and the Klein Zwartberg, a strong anticline of Table Mountain sandstones, in the distance. The gorges of Buffels river are seen on the left in the foreground and background (see note in text).

tudinal synclinal valley and lies on the back slope of the next anticlinal ridge. A photographic view showing part of these features, taken from the floor of Buffels River gorge, is reproduced in plate 48, figure 1.

A view looking southward from the same knob on the wrinkled monoclinal ridge is presented in figure 6. Here the basal member of the Witteberg sandstones is seen with northward dip forming a ridge in the farther foreground. When this ridge is followed westward its determining stratum is seen to bend around, so as to form a sharp turn in the ridge crest. How it is then continued, or whether it is torn or cut off by a local fault, I can not say. Klein Zwartberg is shown in the distance, with the deep gap of Buffels river on the left; subordinate Bokkeveld ridges occupy the intermediate lowland. It should be avowed that this figure is composed of two sketches; the foreground was drawn looking southwest; the background, looking south. The two sketches have been brought together by swinging the background about 45 degrees to the right of its true direction with respect to the foreground, thus giving the incorrect impression that the near and far ridges are convergent, while as a matter of fact they are essentially parallel. The barrenness of this landscape was a surprise to me; the view here drawn included only one house in the river valley. A few flocks of goats and sheep were seen on the ridges, where they seemed to do well, although we saw little or no grass among the peculiar plants of this arid region. The dryness of the climate by which the barrenness of the Karroo is caused does not seem to be due largely to the desiccation of rain-bringing winds by the mountains that lie across their path, for in that case the mountains themselves ought to be fairly well watered on their windward (southern) slopes, and this does not seem to be the case. The dryness is more largely determined by the insufficient equatorward migration of the belt of subtropical rains of the South African winter season, and thus resembles the dryness of Lower California, where rainfall is extremely scanty, although the ocean lies directly alongside of the desert coast. The tracks of the cyclonic areas, from which the rainfall of the subtropical belts is chiefly derived, do not appear to run far enough toward the equator, even in the winter of the southern hemisphere, to water the Karroo. On the other hand, the thunderstorm rains which water the interior highland during the southern summer do not occur very often so far south as the Karroo. Thus the Karroo remains as a dry belt between two areas of moderate rainfall, one of winter, the other of summer rains. It is important to understand this matter in connection with the climate of the Dwyka glacial period, which is considered in a later section.

TABLE MOUNTAIN RANGE AND ITS FELLOWS

We learned from Mr Rogers that the anticlinal Zwartberg is a typical example of its system. In this respect the east-and-west Cape Colony

ridges present a strong contrast to several members of the north-and-south mountains which rise near the Atlantic coast in the Cape Town district, and of which Table Mountain range is a well known outlying example. They all consist, like the east-and-west ridges, of Table Mountain sandstone, but most of them seem to be of more or less distinctly synclinal structure, or the lower edges of down-faulted masses, while the lowlands between them are not occupied by younger strata, but are worn down on the unconformably underlying Malmesbury series of steep dipping slates and quartzites. The ridges are bold, rugged and barren, as in plate 49, figure 1.

Over much of this tract that we crossed on the way into the interior from Cape Town the lowlands are reduced to gently undulating local peneplains, apparently with respect to present sealevel, sometimes interrupted by domes of intrusive granite, as north of Paarl. A belt of sands, which lies on a slightly depressed part of the lowlands, constitutes the "flats" by which the Table Mountain range is united to the mainland, thus apparently repeating the relation in which the rock of Gibraltar stands to the mainland of Spain. The exceptional height reached by the Malmesbury beds in Signal hill, Cape Town, is evidently due to a recent removal of a cover of Table Mountain sandstone like that which still caps Lions head a little farther south, both of these being only small instances of what Table Mountain range is on a larger scale.

The contrast thus presented between mountains of the same formation, Table Mountain sandstone, of anticlinal structure in one district and of synclinal structure in another not far away, is manifestly to be explained not by any difference in the age of the two districts, but simply by the difference in the attitude of the resistant mountain-making sandstone with respect to the controlling baselevel in the present cycle of erosion. In the district of the east-and-west ranges the folds of the heavy sandstone have a relatively deep-lying position; the synclines there are still below baselevel, while the anticlines rise above baselevel high enough to have been stripped of the overlying weaker Bokkeveld beds, and therefore to stand up in effective relief, yet not so high as to be breached along the axis and thus converted into paired monoclinal ridges, as so often happens in the case of the Medina anticlines in Pennsylvania. In the neighboring southwestern district of the north-and-south ranges the general attitude of the Table Mountain sandstones, before erosion swept so much of them away, must have been much higher; for here the anticlines are completely destroyed (their destruction probably having been accomplished in an earlier cycle of erosion than the one now current), and only the lowest-lying parts of the synclines or down-faulted masses now remain.

Indeed, the discontinuity of such ranges as that of Table mountain and of Riebeecks kasteel, some 40 miles to the northeast, show that even the synclines of Table Mountain sandstones have been worn away along a large portion of the length of their axes, the residuals that still survive probably being their lowest parts. This southwestern coastal district is so open that movement is easy in any direction across the peneplain that has been worn down on the older rocks, except where the isolated remnant mountains stand up.

There was so often occasion during our journey across the farther interior country to speak of its aridity, as in the Karroo and along the eastern border of the Kalahari, or of its monotony, as on the broad plains of the Veld, that there is all the more reason for making mention of the often attractive landscapes in the southwestern district of the Cape Colony. The lower lands there frequently possessed a pleasing modulation of surface, and even in the late winter month of our visit the fields seemed hospitably inclined to support the colonists. True, the mountains by which the lowlands are interrupted were of bare and ragged rocks, with no forest cover, and indeed with scanty vegetation of any sort; but they were of bold and picturesque outline—a strong background for the view from neat villages across fields in open vales and on lower hills. It is possible that the landscape hereabout may have a more austere aspect in the autumn after the dry summer; but when we saw it, near the opening of spring, it was agreeably appealing, with a homelike quality that was sadly absent elsewhere.

On going farther inland the heavy Table Mountain sandstones form more continuous ridges, because the general altitude of the synclines there concerned decreases. Among these longer ridges movement is much constrained. The railway has to make a long detour northward to the oblique gap of Berg river, in the Drakenstein ridge (not to be confounded with the Drakensberg mountains of Basutoland, much farther northeast), by which to reach a north-and-south anticlinal valley; then a long turn is made southward to reach the Hex River gorge, where the railway turns northeastward (over the letters TO in Capetown in figure 1) in the next range of Table Mountain sandstone, the southern termination of the Cedarbergen. It is through this gorge that access is gained to the open inner country of the Great Karroo, worn down to a lowland on the weak Bokkeveld beds. It may be noted that Hex River gorge, a superb exhibition of erosion in the massive sandstones, is peculiar in being located near the axis of a northeast-pitching syncline, formed where the north-and-south system of folds joins the east-and-west system. The river is furthermore peculiar in flowing against the pitch of the synclinal axis,

opposite to the course that a consequent river would take. The ridge on the western limb of the syncline was seen to decline and end some 20 or more miles north of the gorge, and we were told that its ending was due to a north-pitching anticlinal roll in the determining sandstones. All this adds new features of resemblance to the Allegheny ridges, where streams frequently flow outward from a synclinal valley near the apex of the inclosing synclinal mountain and where zigzag mountain crests are of frequent occurrence.

The contrast of the anticlinal and the synclinal mountains just referred to is of value as an aid in dispelling the myth, so long current in geological literature, that anticlines are weak structures and that synclines are strong structures; that anticlines, naturally prevalent in young mountains, are unusual or abnormal in mountains of great age, where synclinal ridges should prevail. The Cape Colony ranges agree with the Alleghenies of Pennsylvania in proving that whether the structure be anticlinal or synclinal is of secondary importance, in so far as resistance to erosion is concerned; the prime factors which determine relief are in the first place the relative resistance of the formations involved, and in the second place their attitude with respect to the controlling baselevel. It is of course true in general that if a region of folded structure be worn down below the level of the deepest folds, so as to expose the unconformably underlying formations, the synclines will, other things being equal, survive the longest; but such a condition is seldom met with. Moreover, when the general statement is made that anticlinal ridges are exceptional and synclinal ridges are prevalent in mountains of great antiquity, no mention is made and no reference is intended to the complete obliteration of the folded structures, as in the ideal case just conisdered. The general statement is based on an essential misconception, for the correction of which the Cape Colony ridges and the ridges of Pennsylvania may be confidently appealed to. Anticlines are not inherently weak structures, nor are synclines essentially strong structures. In old mountains synclines of relatively weak rocks are worn down, while synclines of hard rocks stand up; likewise anticlines of weak rocks are worn down, while anticlines of strong rocks stand up; hence it is the nature of the rock and its attitude with respect to baselevel, and not the anticlinal and the synclinal structure, that are dominant in determining these residual reliefs.

PLANATION SURFACES IN THE KARROO

During our excursions from Laingsburg we saw an excellent example of a broad and smooth planation surface or terrace, truncating the strongly folded Witteberg, Dwyka, and Ecca beds and strewn over with

quartzite boulders and cobbles from the neighboring Witteberg ridges—a plain of irredeemable barrenness, though not without plant growth. This relation is shown in figure 7. The general location of the terrace is indicated in figure 2. The terrace is evidently the ancient valley floor of the Buffels River system, in the old age of an earlier cycle. The valley floor was broadly opened on an area of moderately resistant strata, after the river had cut down so deeply in the Leeuw Kloof poort of the Witteberg ridge next farther downstream that further deepening became extremely slow. The reduction of the surface to a plain must have been largely aided by the general wasting down of the minor ridges as well as by the lateral swinging of the streams. The distribution of the coarse cobbles over the plain seems to have been the work of sheet-floods, such as become peculiarly effective in the later stages of a cycle of erosion, particularly in a region where occasional heavy downpours of rain occur. The plain is now dissected by Buffels river and its branches, whose valleys have reached a stage of middle or late maturity, at a level

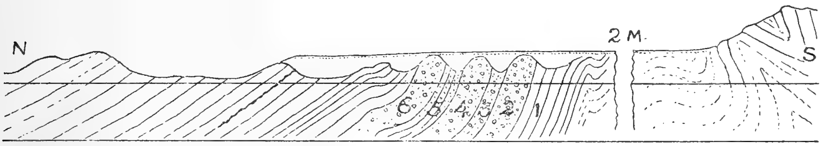

FIGURE 7.—*Detailed Section of the Witteberg, Dwyka, and Ecca Series.*

Witteberg strata are on the right, Dwyka in the center, and Ecca on the left. The locality is five miles southwest of Laingsburg.

of from 300 to 500 feet beneath that of the plain. A view of the terrace plain, looking southward toward the ridge from which the cobbles are derived, is given in plate 52, figure 2. A view of the valleys dissected beneath the plain, taken from about the same point as the preceding view, but looking west-northwest, is given in plate 48, figure 1; some of the higher knobs in the ridges shown rose, however, above the terrace level. We were told that several other examples of cobble-strewn terraces are known elsewhere among the east-and-west ridges. Some of them have been described by Schwarz.

The chief reason for mentioning this terrace is to draw attention to its possible explanation by change of climate rather than by change of continental attitude or altitude, the latter explanation having been generally accepted on our excursion. It is well known that a valley floor will be widened by the swinging of a river that has reached the graded condition—that is, the condition of balance between its capacity to do work and the work that it has to do; that the graded condition is one of great delicacy, and that any change in river volume or river load will tend to

cause the abandonment of the previously established graded condition and the development of a new grade. It is true that the variation of river slope thus determined may be very small, but it is also true that a small variation of slope will cause a significant change in the way of aggrading or of degrading in the upper course of a river several score or several hundred of miles in length. It is, moreover, generally believed that climatic changes of importance have taken place in the Pleistocene time; hence the effects of such changes should be looked for in the valleys of graded rivers, just as they are looked for where glaciers have been formed and where lakes have expanded and contracted. While these principles are familiarly accepted, their application to the problem of terracing is less general than it should be. One of the most important examples of such application is that offered in W. D. Johnson's admirable paper on the High plains of Colorado and Kansas, in which variation of climate rather than variation of continental attitude is appealed to as the effective cause of the aggradation of the plains by the rivers flowing from the mountains and for the later dissection of the aggraded plains by the same rivers. Another example of the same kind is to be found in the first volume of Pumpelly's report on his Carnegie expedition to Turkestan, in which Ellworth Huntington describes certain terraces associated with glacial moraines in the valleys of the Tian Shan mountains of central Asia. I can not attempt to determine how far these authors are right in thus appealing to climatic variations in explanation of the phenomena that they describe; but it is safe to say that, until variation of climate and variation of continental attitude are both duly considered and some means of distinguishing between their effects is discovered, it will be premature to assume that either cause is fully responsible for the observed effects.

The Buffels River terrace is about 100 miles from the mouth of its river system. When the terrace was formed Buffels river was probably well graded all the way to its mouth, a tolerably smooth and gently sloping channel being then established even in the mountain gorges that it traversed. At present, however, the river is not very smoothly graded in certain parts of the Leeuw Kloof notch, and hence is probably even less smoothly graded in the harder rocks of the notch in the Klein Zwartberg. When an even grade is fully established later in the present cycle, the valley about Laingsburg will have been significantly deepened and greatly widened. The total depth of erosion in the terrace or the former valley floor to the equally well developed future valley floor, great as it may seem when only the Laingsburg district is considered, would be brought about by a change of river slope amounting to only 10 or 15 minutes of

arc in the 100-mile Buffels river from Laingsburg to the sea, and it can hardly be doubted that so small a change of slope would be easily producible by climatic control without any change whatever in continental attitude. On the other hand, it is entirely possible, as far as purely theoretical considerations are considered, that the dissection of the terrace here described may be due wholly to revival of river erosion by crustal movement, independent of climatic change. When fuller details are at hand regarding the distribution of similar gravel-covered terraces in the valleys of the Cape Colony ranges it may be possible to choose between these alternative hypotheses. It will then be important to examine the distribution of terraces with respect to the direction of the rivers that they accompany, for under the hypothesis of climatic change all the rivers of the region will terrace their valleys, irrespective of their direction, the depth of terracing being dependent on the amount of climatic change, on the distance of the terrace from the river mouth (measured along the river), and on the time since the change of climate occurred. On the hypothesis of regional warping or tilting, terraces will be much better developed along rivers whose courses are in the direction of tilting than along those whose courses are in the opposite direction.

It may be mentioned that some members of our excursion party seemed to regard the Buffels River terrace as possibly a result of the difficulty encountered by the river in deepening its notches through the mountains farther down valley without any aid from climatic change or from revival by tilting—that is, the terrace was regarded as a possible product of a continuous cycle of erosion, uninterrupted by land movement and unaffected by climatic change. Such an explanation is untenable in the case of a river which is cutting a notch in an anticlinal ridge; for here the difficulty of cutting increases with increased depth of cutting below the anticlinal crest, while the valley eroded beneath the terrace indicates a relatively sudden increase in the efficiency of erosion. Such an increased efficiency might be associated with a river which had been cutting a notch through a synclinal mountain, for the broadened valley floor eroded in weaker strata upstream from the notch might be trenched when the river had cut down through the harder synclinal strata into weaker underlying strata. The Buffels River terrace is evidently associated with notches cut in anticlinal ridges, and hence can not be explained merely by the varying relations of the river to the hard rocks in the notches.

THE DISSECTION OF GRADED MOUNTAIN SLOPES

On the eastern side of the open anticlinal valley between the Drakenstein range (the southern part of the Olifants River mountains) on the

west and the Cedarbergen on the east, it was noted that the western face of the last named range presented rather well graded slopes, in which narrow obsequent ravines were sharply cut. It did not seem as if the smooth slopes and the sharp cut ravines could be due to a single set of erosive processes acting together in an undisturbed physiographic cycle. Some change seemed to have taken place whereby the ravine streams have been enabled to incise their steep courses beneath the open slopes that they should have formerly occupied on the graded mountain side. Something of the same kind was suggested in the distant view of the north slope of Klein Zwartberg, as is indicated in the sketch, figure 6. Similar features are described by Schwarz (*a,* 49), who gives a figure in which the contrast of graded mountain slope and incised ravines is even more distinct than in the cases that I had seen; but, as in the other examples of relatively recent dissection described by the author cited, this one is ascribed essentially to the effects of stream revival by continental movement. It is quite possible that such may be the case; but it seems to me desirable to maintain an open mind on that point for the present, until it can be more fully determined what share climatic change may have produced here as well as in the production of terraces.

The Dwyka Formation

GENERAL FEATURES

Extent and stratigraphic relations.—The Dwyka formation, probably of Permian date and of variable thickness up to 1,000 feet or more, is the lowest member of the Karroo system, which covers some 200,000 square miles in the interior of South Africa between latitudes 26 and 33½ degrees south. The area of the Dwyka is shown in figure 1. It reaches the eastern coast at various points in Natal and Cape Colony between latitudes 29 and 33½ degrees south. It rests for the most part unconformably on a grooved and striated surface of older rocks, but along its southern border it follows conformably a series of sandstones and shales. It consists chiefly of an unstratified and consolidated clastic groundmass with subangular or rounded scraps, stones, and boulders of many kinds, the finer textured stones and boulders being usually well scratched. It is conformably overlaid by a coal-bearing series of shales and sandstones. It lies for the most part essentially undisturbed, but along its southern border it has been strongly folded, along with older and younger strata, in a series of anticlines and synclines, which form the Witteberg ranges described in a preceding section. The area now occupied by the Dwyka is

certainly less than its original area, for its outcrops everywhere indicate a loss by erosion.

The glacial origin of the Dwyka formation is as unquestionable as is that of the drift sheets of northeastern America or of northwestern Europe; but, singular to relate, the Permian ice-sheet by which the Dwyka was formed moved in general *southward,* from the region of the equator toward the region of the pole.

Accounts of the progress of geological investigation in South Africa with particular reference to the recognition of the Dwyka formation as of glacial origin are given by Corstorphine, Hatch and Corstorphine (10-18, 197-210), Rogers, and Mellor. It is probable that the glacial origin of the Dwyka would have earlier found a more general acceptance if various other origins had not been suggested for it by several South African observers.

My object here is to set forth certain observations that I made on the Dwyka with its associated formations and certain conclusions to which these observations led.

The capital letters in figure 1 are the initials of the localities that our parties visited; the small letters are initials of especially significant localities described by Rogers, Mellor, Anderson, and others, which we did not see and to which reference is made farther on. In speaking of the unstratified parts of the Dwyka, I shall avoid the term "congolmerate" and adopt Penck's term, *tillite,* meaning thereby a rock formed by the consolidation of glacial till.

The Dwyka near Matjesfontein.—Our first sight of the Dwyka was on the excursion led by Mr Rogers, as already described. We reached Matjesfontein, in the Karroo district, on the morning of August 20, and there found ourselves in the Karroo, the dry interior country of east-and-west ridges and valleys that lie between the great interior highland and the Cape Colony ranges. Here we had a walk of about 5 miles northward from the neat railway village across broad ridges and valleys of Dwyka and Ecca. A few miles to the south rose a long, even crested anticlinal mountain of Witteberg sandstones. Farther away in the north rose the escarpment of the plateau country of horizontal Ecca and Beaufort formations. The whole district hereabout is treeless; the water-courses were nearly all dry at the time of our visit. The surface of the ground was abundantly exposed between the scattered plants, and the exposures of bare rock were plentiful where a thin, stony soil had not accumulated. The following facts were noted.

The matrix or groundmass of the Dwyka tillite is here dark, fine-grained, unstratified and trap-like in appearance; it contains numerous

small angular specks and scraps of many sorts of rocks, as well as pebbles, cobbles, and boulders up to two or three feet in diameter. We found pieces of granite, amygdaloid, banded jasper, quartzite, quartz, limestone, slate, and several kinds of sandstone. It seemed as if every piece of the finer grained sandstones, especially of a certain fine reddish sandstone, found in the tillite or loose on the surface near the point where it was weathered out, was distinctly and irregularly scratched. It would be impossible to distinguish these scratched stones from stones of the same texture found in the till of New England. The larger pieces of sandstone and quartzite were often grooved, faceted, and regularly striated as well as irregularly scratched, all these markings being characteristically of glacial origin. These surface details are soon lost as the weathered cobbles and boulders creep and wash down the hillsides. The lack of scratches on many of the coarser grained stones is precisely what might be expected in an ancient tillite, if we judge of it by modern glacial formations; for it must not be forgotten that by no means all the stones in Alpine moraines or in Pleistocene till sheets are striated.

Some of the pebbles in the tillite near Matjesfontein were slightly sheared, some were indented, others wore pointed "beards" of the sheared matrix. Pebbles thus affected, but without surface scratchings, are not uncommon in various nonglacial conglomerates that have been compressed and tilted; for example, in some of the Carboniferous conglomerates near Boston, Massachusetts, and Newport, Rhode Island. It therefore seems reasonable to refer the shearing and denting of the Dwyka pebbles to the regional deformation which the whole series of formations has suffered in the Karroo, and to regard these as secondary features that have no bearing on the scratches, which are primary features of the formation. None of the outcrops that we here identified as Dwyka by means of their included stone fragments exhibited distinct stratification, but there seemed to be a heavy bedded structure which determined the development of linear topographic features; in this respect our observations on the following day near Laingsburg are more significant. The normal dark blue color of the unweathered tillite was well shown in several recent cuts along the sides of the post road that we followed; the weathered surface is a dull yellowish gray or brown. This change of color recalls that which takes place when the bluish Pleistocene till of the northern United States is attacked by the weather and rusted to a yellowish gray. The larger forms of this district indicated several folds of moderate intensity, especially in relation to a high synclinal hill a few miles away, which was identified as consisting of the overlying Ecca sandstones by Mr Rogers from his previous studies here; but the near view of the Dwyka gave us

no indication of its attitude. The rock frequently weathered into sharp pinnacles or spikes, as in plate 50, figure 1, from 1 to 3 feet high, the result of flaking and splintering along surfaces that we afterward found to stand usually about at right angles to the tillite sheets. We made no attempt to measure the thickness of the Dwyka here, as its structural relations were too obscure, nor could we at this place safely make out its structural relations to the underlying or overlying formations.

The result of this first day's observations was to convince us that all marine, lacustrine, fluviatile, eolian, and volcanic processes must be excluded from any share in making so much of the Dwyka as we had seen, and to prepare us to accept the explanation given for it by the majority of South African geologists, if its outcrops elsewhere should bear equally unmistakable signs of glacial action.

The Dwyka ridges near Laingsburg.—A short run by train on the morning of August 21 carried us from Matjesfontein about 20 miles eastward to Laingsburg, where we drove out 5 miles southwestward in two-wheeled Cape carts to the dry ravine of Witteberg river (see figure 2), a branch of Buffels river, which here flows southward, transversely to the general trend of the Karroo ridges and valleys. The upper Witteberg branches have eroded valleys from 300 to 500 feet deep beneath the planation surface that is strewn with cobbles of Witteberg sandstone, as has already been described on an earlier page. The north-south section of the Dwyka at this locality is shown in figure 7, from which it appears that the Dwyka, along with the underlying Witteberg and the overlying Ecca formations, has been strongly tilted and eroded. The Dwyka stands nearly vertical, with steep dip to the north. The lower 1,000 feet, for the most part unstratified, carry pebbles, cobbles, and boulders; the upper 700 feet of the formation, as it has been defined by Rogers and others, is made up of ordinary stratified sandstones and shales. This upper division showed no peculiar features; it might have been well associated, as far as we could see, with the overlying Ecca, from which it was arbitrarily but conveniently divided by a persistent stratum of dark shales which weather whitish, with an efflorescence of gypsum (shown by an undulating line in figure 7), so as to be traceable as a gray band on the ridge slopes for miles around. Our attention was particularly directed to the lower 1,000 feet of the Dwyka, where six members are to be noted, the first, third, and fifth being worn down in longitudinal east-west valleys, the second, fourth, and sixth standing up as ridges 200 or more feet in height. The ridge-making members are each 150 or 200 feet thick; the valley-making members share the rest of the total (see figure 7).

The lowest or basal member consists of shales, distinctly stratified, and contains small and scattered fragments, up to a foot or so in diameter, of various rocks. The fragments are rarely more than 3 or 4 inches in diameter near the base of this member; they are larger, up to 10 or 15 inches in diameter, and more frequently striated, 50 or more feet above the base. It is only by the presence of these fragments that the basal member is to be distinguished from the underlying Witteberg shales, for the passage from one to the other is not marked by an unconformity or distinct change of composition, except for a discontinuous layer of quartz rock that sometimes separates the two. As none of the formations in the Karroo series contain marine fossils and as freshwater or land fossils occur at several horizons, it was inferred that the basal member of the Dwyka was deposited either in a sheet of water or by a river marginal to an ice-sheet; preference was given to the former, as far as our observations went, because of the presence of the scattered scratched stones, which are thought not to characterize river deposits in general, and because of the absence of gravelly layers and cross-bedded structure, which should be expected in river deposits not far from an ice-sheet. Thus interpreted, the basal member of the Dwyka differs from the next underlying layers of the Witteberg in marking a time when an ice-sheet had advanced near enough to add stones, carried by floating ice, to the deposits of a body of standing water. In the absence of marine fossils, the water seems to have been that of a lake. The side from which the ice advanced is not indicated by anything that we saw in this district, but it is well proved to have come from the north by observations elsewhere, of which more is said below.

The second member of the Dwyka is a characteristic sheet of tillite—compact, dark bluish when fresh, yellowish brown when weathered, entirely unstratified except for a single vertical layer of conglomerate a few feet thick—which is exposed in a fine notch, or "poort," where Witteberg river has cut through the ridge. A view of the eastern wall of the poort is given in plate 50, figure 2; a similar view is given by Rogers (plate on page 167). The dominant joints, many of which are here shown, divide the mass into prisms that stand about square to the tillite sheet—that is, they dip gently to the south. The bedding is nearly vertical, as is shown by the layer of conglomerate near the left margin of the view. On the top of the ridge (plate 52, figure 1) the prisms are weathered into "bales" and "pillows" by the loss of their corners, and the pillows are reduced to curious spike-like fragments by flaking and splintering on surfaces of what seemed to be incipient schistosity. The points of the pillows and spikes often stand out on the slopes of the ridge, giving it a very peculiar

expression. The tillite contains abundant fragments, small and large, of many kinds of rocks. It was easy to find striated stones on the slope of the ridge, where they had lately been weathered from the matrix. It was noteworthy that this heavy tillite sheet lay evenly on the basal stratified member without any discoverable disturbance or unconformity. In this it corresponds to various sheets of till in the upper Mississippi valley, which frequently lie conformably on stratified deposits. It is evident that the tillite indicates the arrival of the ice-sheet, whose coming had been foreshadowed by stones in the basal member, and that the ice-sheet acted here as an aggrading agent, in striking contrast to its behavior farther north, as will appear later.

The third member of the Dwyka is worn down in a well defined longitudinal valley, although it is not distinguishable in appearance from the tillite of the ridges that inclose it. Its structure is well shown in abundant exposures in the dry channel of Wittebergs river, which turns along the valley for half a mile between two notches. Small boulders of many kinds are here seen in the tillite. This valley is shown in plate 52, figure 1, between ridges of the second and fourth members, which turn gently to the left in the distance.

The fourth member makes a ridge like the second. It is a sheet of tillite, but seems to be divided about the middle by a weaker sheet—perhaps by some stratified layers that we did not see—for the ridge is somewhat grooved along the top on each side of the notch that we came through.

The fifth member is again stratified, and here stands vertical, as in plate 51, figure 1. It contains scattered stones, like the basal member. The upper surface of the fourth member and the lower surface of the sixth seemed to be closely conformable to the stratification of the fifth. The fifth layer was taken to indicate a withdrawal of the ice-sheet which had formed the second, third, and fourth members and a resumption of aqueous conditions similar to those which prevailed during the deposition of the basal member.

The sixth member is a resistant, ridge-making sheet of tillite, not so thick as the fourth, but of the same nature. It appeared to be conformably followed by the overlying sandstones and shales. Like the other unstratified sheets, this one weathered on transverse joints and surfaces of incipient schistosity into pillows and spikes, giving the crest and upper slopes of the ridge the appearance of being built up in part of bales and sticks laid crosswise. This sheet of tillite manifestly indicates a return of the aggrading ice-sheet—that is, of an ice-sheet which by its own weakening action here laid down the detritus that it had dragged from elsewhere.

The chief results of this day's excursion were: First, the repetition of many significant features that had been noted the day before at Matjesfontein and which were thus shown to be of more than local value; second, the recognition of the composite structure of the formation, indicating at least two advances of an aggrading ice-sheet into this district; third, the fuller evidence of induration, deformation, and erosion suffered by the Dwyka and other formations of the Karroo series, from which it is manifest that we have here to do with a glacial formation of much greater antiquity than that of Pleistocene date.

A second excursion from Laingsburg, August 22, took us down Buffels river (see figure 2) to the Witteberg range, as already described. A generalized section some 10 miles in length is given in figure 8, from which it appears that the structure of the district is characterized by many strong east-west folds, causing the Dwyka to reappear in successive outcrops along the east-west ridges and valleys. The southern continuation

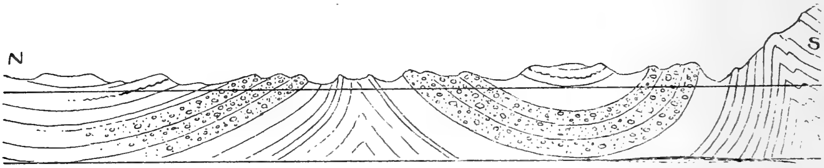

FIGURE 8.—*General Section of folded Witteberg, Dwyka, and Ecca Formations, South of Laingsburg.*

Length of section, about 10 miles. This is the northern continuation of figure 3.

of this section is given in figure 3. We no longer gave special attention to the structure or the composition of tillite, for a passing glance now sufficed to show that it repeated persistently all the essential features previously recognized, and a brief pause sufficed to find striated stones on almost every tillite outcrop; but we examined the topographic features of the formation with some care, because they showed that the subdivisions of the Dwyka and their conformable succession from the Witteberg below to the Ecca above, as recognized the day before, were maintained for 10 or more miles along and across the strike of the ridges. This encouraged us to believe that further exploration may enable South African geologists to establish well defined glacial and non-glacial epochs in the Dwyka period—an important matter to which but little attention seems to have been given, although Dunn and others have reported the occurrence of alternating shales and tillite beds at various points. Some further account of the ridges of Witteberg sandstone which rise to the south of this Dwyka area is given in an earlier section of this paper.

The glaciated Dwyka floor near Ngotshe, Vryheit.—Three members of Rogers' party, Coleman of Toronto, Penck of Vienna, and I, left the

others at Laingsburg and went by train via Johannesburg to Vryheit (VY, figure 1) in Natal, to join a party led by Mr W. Anderson, geologist of that colony, and Dr G. A. F. Molengraaff, formerly geologist to the South African Republic. From Vryheit we drove some 30 miles northward, past a dolerite-capped table mountain called Hloban (Hl, like the Welsh Ll), where General Buller some twenty years ago defeated the Zulus with the aid of the Boers and won the Victoria cross; past the ruined farm of General Botha, around which the long avenues of Eucalyptus still flourish, to a small inn on one of the Emmet farms, called Waterval. The next day we drove a dozen miles farther to a valley on the headwaters of Pongola river, which flows down the eastward slope where the interior highland descends toward the Indian ocean. There, on August 24, we saw the horizontal Dwyka-Ecca series, 2,000 or 3,000 feet thick, rising in a dolerite-capped table mountain or plateau remnant, called Ngotshe (N, figure 1; the name begins with an unwritable Zulu "click"), and resting unconformably on a floor of Barberton beds, hard slates of early Paleozoic or older date, which dipped 24 degrees to the northwest. This district was explored by Molengraaff in 1897, when he found several highly significant contacts of the older and younger formations in certain dry ravines on the north slope of the Ngotshe mass; it was one of these contact localities that we came to see.

The Dwyka is here closely packed on an uneven surface of Barberton beds, which are beautifully rounded, grooved, and striated—in a word, well glaciated. Sometimes a ledge of the scoured and striated surface overhangs by a small amount; the Dwyka is then packed in beneath such a projection. The ravine that we followed gave excellent sections of the tillite, as in plate 51, figure 2, and often exposed the underlying Barberton surface with more or less distinct grooving and striation, and with more or less Dwyka tillite (plate 53, figures 1 and 2) resting on it, for a quarter of a mile or more. The grooves and striations on the Barberton hold their courses unchanged as they pass under the tillite cover, reminding one of the manner in which the wheel tracks in the Roman forum pass straight under the cover of detritus at the side of the modern excavation. The relief of the Barberton surface seemed to be of moderate measure in this immediate locality, probably not more than 20 or 30 feet in the dry ravine that we followed; but the relief of the present surface is to be measured in thousands of feet, from the dolerite-capped remnants of the plateau of the horizontal Karroo series to the bottoms of the larger valleys, deep cut in the ancient Barberton slates.

The Dwyka itself repeated all the features previously noted. A finely striated 5-foot boulder, with Penck's half-meter hammer handle lying

on it, is shown in plate 52, figure 2. The largest boulder that we saw here was a block of Barberton slate 6 feet through. All the significant facts noted here—the rounding and striation of the older rock floor, the unstratified structure of the Dwyka, the varied composition of the included fragments, large and small, their subangular form and frequently scratched surfaces—are absolutely typical of strong glacial action.

A special interest attaches to the direction of ice-movement as recorded in the grooving and striation of the Barberton slates. The alignment, roughly north and south, is manifest at a glance. After careful inspection of several localities we came unanimously to the conclusion that the motion of the ice-sheet had been southward. The true bearing of the striations was south 25 degrees east. As will be seen later, this agrees in a general way with the direction of ice-motion determined at a number of other locailties, and thus indicates one of the most extraordinary peculiarities of the South African Permian glaciation—the ice-sheet in latitude 27 moved from the region of the equator toward the region of the pole.

We followed up one of the larger ravines southward along the west base of Ngotshe mountain and ascended through the whole thickness of the Dwyka formation—the greater part of 1,000 feet, as I estimated it—to the lower members of the overlying Ecca. The division between the two formations was drawn where the shales or sandstones begin to be free from included stones. The Dwyka is shown to consist of several subdivisions of stronger and weaker members by the occurrence of well defined benches, scarps, and slopes that contour about horizontally around the hillsides. Some of the weaker members were stratified, as they were at Laingsburg, but their sequence seemed to include a greater number of alternations of tillite and shales here than there, especially near the upper part of the formation. The overlying Ecca followed in perfect conformity, as far as we could see. It contains a good seam of coal several hundred feet above the Dwyka; it is capped at the top of the mountain with a sheet of dolerite, as is so often the case in the strongly dissected belt of country where the eastward descent is made from the plateau of the High Veld to the coastal lowlands.

This fourth day on the Dwyka was most instructive from the contrast presented by the unconformable succession of the tillite on the glaciated Barberton surface shown here and the conformable succession of the Dwyka members on the Witteberg shales shown near Laingsburg. The contrast is the same as that which is presented between the glacial features of the Laurentian region of Canada and of the northern United States, or between those of Scandinavia and northern Germany, and this

contrast strongly confirms the inference as to the direction of ice-motion, as based on the form of the glaciated floor. We returned to Vryheit on August 27 and to Johannesburg on August 28.

The Dwyka at Vereeniging.—During the stay of the Association at Johannesburg, Penck and I had, through the courtesy of Dr F. H. Hatch, president of the Geological Society of South Africa, a most interesting morning excursion on September 1 at Vereeniging, where the main line of the Cape Town-Johannesburg railway crosses the Vaal river. Half a mile northeast of the railway bridge there is an important section (figure 9) exposed in the river bank, which we saw very well as the river was low at the time of our visit. A small patch of Dwyka is here exposed, with a thickness of 15 or 20 feet, resting unconformably on a local outcrop of the dolomite of the ancient Pretoria series and covered by the horizontal coal-bearing Ecca beds, which occupy most of the country hereabout. We could not find any striation or grooving on the underlying dolomite, but it is very probable that further search will be more successful than ours. The Dwyka had numerous stones and boulders, up to

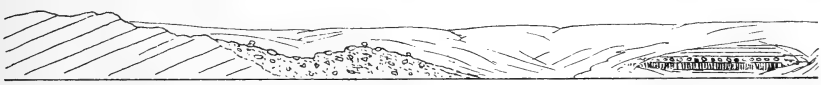

FIGURE 9.—*Local Section on the Bank of the Vaal River at Vereeniging, Transvaal.*

Dolomite on the left; Dwyka tillite in center; coal, conglomerate, and shale of the Ecca series on right. Length, about 400 feet.

4 feet in diameter, many of them well scratched. In its upper part was a layer of sandstone, dipping northeast 15 or 20 degrees. The contact of the Ecca on the Dwyka was not seen, but the relative attitude of the two formations suggested a slight unconformity, possibly due to the originally uneven or sloping surface of the Dwyka rather than to any significant amount of deformation or erosion. The Ecca included a thin layer of coal covered with two feet of ordinary conglomerate of waterworn pebbles, followed by shales and sandstones. It should be mentioned that this and other conglomerates in the Ecca have been described as "Dwyka" by some observers, thus giving rise to the opinion that coal beds and glacial deposits alternated in this district. Such a conclusion did not seem to us well founded. It is quite possible that the pebbles in this bed of Ecca conglomerate came from the Dwyka sheet near by, but there appears to be no other relation than that between them. The use of the term "conglomerate" as a name for the unstratified sheets of Dwyka, with their blunt-ended, scratched stones, as well as for the layers of normally waterworn pebble beds in the Ecca and other formations, may have contributed to the misunderstanding whereby glacial action and coal forma-

tion were so closely associated, and for this reason, if for no other, the introduction of the new term "tillite," as suggested by Penck at the Johannesburg meeting of the Geological Section of the Association, seems desirable.

The general relations of local outcrops at Vereeniging to the older formations as far as Johannesburg are roughly shown in figure 10, drawn with aid from Doctor Hatch. In this connection Hatch's Geological Map of the Transvaal, in Hatch and Corstorphine's book, should be consulted. It is thus seen that the Karroo system, in which the Dwyka and Ecca formations are the lower members, is the latest of five great geological systems separated from one another by unconformities (undulating lines in figure 10). Crystalline rocks, believed to be Archean, form the base of the section north of Johannesburg. On these lie the strata of the Witwatersrand system, with a lower member including the banded jaspers of the Hospital Hill series, which resemble similar rocks in the region of

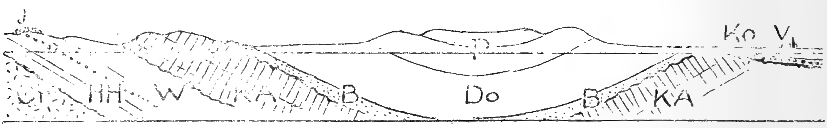

FIGURE 10.—*General Section from Johannesburg to Vereeniging.*

J, Johannesburg; V, Vereeniging; Cr, basal crystalline rocks, exposed north of Johannesburg; HH, Hospital Hill series, the lower part of the Witwatersrand (W) system, in which the gold-bearing "banket" or puddingstone occurs; KA, Klipriversberg amygdaloid, of the Ventersdorp system; B, Black Reef quartzite, Do, Dolomite, and P, Pretoria quartzites, these three forming the Pretoria or Potchefstroom system; Ko, Karroo system, here including the Dwyka tillite and the Ecca shales.

lake Superior, and an upper member including the famous gold-bearing Banket or "puddingstone" of the Rand. Next comes the Ventersdorp system, here chiefly composed of the volcanic rocks of the Klipriversberg amygdaloid. Then follows the several members of the Potchefstroom system (according to the terminology of the authors above cited), first the Black Reef quartzite, here unusually thin and unimportant topographically; then the heavy dolomites, from which the water supply for Johannesburg is largely derived; and last the Pretoria quartzites. The unconformities below and above the Ventersdorp system are not marked by striking differences of dip; the unconformity by which the Karroo system is separated from all the older rocks is much more pronounced. These structural features will be seen to be of importance when the topography of Dwyka time is considered in a later paragraph.

A mile or two northeast of Vereeniging the Sugarbush branch of the Vaal river opens a short section with Klipriversberg amygdaloid at the base, unconformably covered by Black Reef quartzite and its associated

dolomite, and these followed unconformably by the Dwyka—all as identified by Doctor Hatch—while the Ecca strata are not far away. It is thus seen that the streams hereabout are cutting through the general cover of Dwyka and Ecca and making a beginning of superposition on the unconformably underlying formations. This process has apparently been advanced to a later stage some 40 miles farther south, where the Vaal river wanders most irregularly on a tilted series of older formations, the Karroo beds that once presumably covered the older rocks in that district having been widely worn off.

The coal seams of the Ecca are extensively mined at and near Vereeniging; one of the fine grained Ecca sandstones is quarried for building stone and is found to contain good prints of ferns (Glossopteris). A shaft is sunk in the Dwyka, and the clay of the tillite, here light bluish gray and imperfectly indurated, is brought up for use in making fire-brick. The waste heaps near the shaft contain many beautifully striated stones of typical glacial form.

The chief result of this day's excursion was the larger view that we gained of the pre-Dwyka conditions in the northern part of the Dwyka area. The harder members of the Pretoria series northwest of Vereeniging rise in rounded hills 300 or 400 feet over the peneplain—one might well say plain—of erosion that has been broadly developed on the weaker beds of the Karroo series. A stronger relief than this must have prevailed when the Dwyka was forming, for the hills lost some of their original height during the accumulation of the later members of the heavy Karroo series, which probably once rose hundreds of feet above the present plain, as well as during the subrecent removal of these higher members; and, moreover, the base of the pre-Dwyka hills is not now seen, being buried under so much of the Karroo series as still remains. Yet the manner in which the pre-Dwyka hilltops come to sight where the streams cut through their Karroo cover suggests very strongly that the pre-Dwyka relief was of rather well subdued form. This is a matter of interest as bearing on the climatic conditions under which the Dwyka ice-sheet was formed.

The glaciated Dwyka floor at Riverton and Kimberley.—My last sight of the Dwyka was in an excursion energetically planned by Penck for a small party to Riverton, on the Vaal river, about 15 miles northward from Kimberley. The heavy diabase of one of the pre-Karroo formations here appears along the river bank and in a small island within the channel, showing a well rounded, grooved, and striated surface, with patches of typical Dwyka still clinging to it here and there. This important locality was first discovered by Stow in 1880. I estimated that we could

here see some 20,000 square feet of distinctly rounded and grooved, but somewhat weathered, rock surface; that at least 1,000 square feet of this still preserved distinct striations of characteristic glacial quality, and that the scattered remnants of Dwyka occupied a few hundred square feet. The general relief of the surface was small. The direction of ice-motion here indicated was to the southwest. Still better exposures of this kind occur half a mile farther up the river, where the remarkable views reproduced in plate 54, figures 1 and 2, were taken and sent to me by the kindness of Professor R. B. Young, of the Technical Institute, Johannesburg, whom we had the good fortune to meet at Riverton. It may be added that two of our party, Mr Lamplugh, of the British Geological Survey, and Doctor Beck, of Freiberg, reported that they had seen the Dwyka on a striated surface of older rock in the great open pit of the Kimberley mine at Kimberley. The upper part of the pit, perhaps a quarter of a mile in diameter, has sloping sides in the weaker beds of the Karroo series for some 300 or 400 feet; the walls then go down vertically out of sight from the surface for 1,000 feet in the harder older rocks, thus indicating the form of this extraordinary "pipe" of "blue ground," the matrix of the Kimberley diamonds. It is at the change from the sloping to the vertical wall that the Dwyka is seen. We were told that it may be examined by following the galleries that are opened there to intercept the ground water from the overlying beds. The striated surface on which it rests was reported to be diabase similar to that which we saw at Riverton. The general form of the glaciated surface was nearly level, as judged from the form of the pit when seen from the surface. When this is taken in connection with what we saw at Riverton, it confirms very well the conclusion reached before as to the small relief of the floor on which the Dwyka rests.

Glaciated Dwyka floors elsewhere.—Other accounts of the striated rock floor under the Dwyka have been published as follows: There are well striated quartzites with striations bearing south 10 degrees west near Prieska, on the Orange river, in Cape Colony, first recognized by Stow (about longitude 23 degrees east; see *p,* figure 1) and recently described by Rogers (pages 155, 159, plates viii and ix). Striations bearing south, magnetic, have been found on the Waterberg sandstones near Balmoral, east of Pretoria, in the Transvaal (about longitude 28½ degrees east; see *b,* figure 1). These are described by Mellor, who adds that the northernmost areas of the Dwyka are nearly in latitude 24½ degrees (pages 117, 118); also by Hatch and Corstorphine (page 209, figure 50). Striations bearing about east and west, the direction of ice-movement not being specified, occur on the Tugela river in Natal (about longitude 31½ degrees east;

see *t*, figure 1), and are described by Anderson (*a*, page 89); and on the Umfolosi river, direction not specified (about longitude 31½ degrees east; see *u*, figure 1), also described by Anderson (*b*, page 60). In the latter report the Dwyka is referred to as the "glacial Ecca conglomerate," a change of name which seems to me regrettable, in view of the wide use already gained by the term Dwyka.

Nearly all the reported observations are thus seen to confirm the general southward motion of the Dwyka ice-sheet, and to indicate that it spread southeast, south, and southwest in a radiating fashion from a central area inferably situated farther north, but not yet determined by observation. The moderate relief of the pre-Dwyka surface inferred from the observations here detailed is confirmed by the accounts given by Rogers and Mellor above cited, and also in various geological sections published by mining engineers, as the result of surface observations supplemented by borings in the search for coal beds in the covering strata or for the gold-bearing Banket in the underlying strata. Anderson's reports indicate a stronger relief for the pre-Dwyka surface near the coast in Natal than appears to prevail in the interior.

SUMMARY CONCERNING THE DWYKA FORMATION

In view of all the foregoing it may be concluded that there is at present no evidence whatever that the Dwyka ice had the form of Alpine glaciers. All reported observations indicate that it was a broad and continuous ice-sheet which spread across about 600 miles of country, east and west, and which advanced at least 500 miles poleward from its apparent source. It moved across a region which bore subdued mountains here and there, but which was reduced to moderate relief by previous erosion over large areas. It seems to have invaded a water-covered area along its southern margin in latitude 33½ degrees south. In the marginal area at least the ice advanced more than once, and after its final recession a climate ensued so favorable to plant life that a number of coal beds were formed in the Ecca series which overlies the glacial deposits. It is noteworthy that demonstrably marine deposits are nowhere associated with the Dwyka, not even in Natal and eastern Cape Colony, where the Dwyka tillite repeatedly reaches the shore of the Indian ocean.

While much has already been learned, much yet remains to be learned regarding this remarkable formation, particularly regarding certain features which are now well known in association with the till sheets of other glaciated areas. In the central parts of such areas stratified gravel deposits of irregular structure and form are commonly found on the unstratified till or on the glaciated rock surface, but no such gravels are

yet reported in connection with the northern part of the Dwyka tillite in the Transvaal. In the peripheral parts of other glaciated areas terminal moraines and overwashed gravels are found bordering the till sheets, but no such accumulations are yet reported from the southern part of the Dwyka in Cape Colony. It is possible that a search with these matters in mind might aid in their discovery.

The climatic conditions under which the Dwyka ice-sheet was formed offer a most interesting subject for inquiry. The chief factors to be considered in this connection are: Altitude of the Dwyka land surface above the sealevel of its time; distance from the continental margin, as the continent was then shaped; form of the Dwyka area and its relation to neighboring mountains and highlands of Permian time; various atmospheric factors, such as composition, temperature, and circulation; certain astronomical factors; and the latitude of the glaciated area, as latitude was then arranged.

THE TOPOGRAPHY OF SOUTH AFRICA IN DWYKA TIME

Evidence has already been given to the effect that the floor on which the Dwyka rests had been extensively eroded and reduced to moderate or small relief in pre-Dwyka time. If the region then drained into the sea, and if it were not farther from the coast than it is today, it must have been a lowland, for only as a lowland could it have been eroded to small relief. If the Dwyka region had been of interior drainage in pre-Dwyka time it might have stood as high or higher than it does now; but in that case it must have been better inclosed from the ocean than it is at present. Such inclosure would have required an extension of the continent, particularly on the east and south, where the Dwyka now reaches or approaches the present coastline, and as a consequence of such continental extension the Dwyka area would have probably been drier than it is today.

As between the two suppositions of a lowland draining to the sea and an interior plateau, the occurrence of marine (Devonian) fossils in the Bokkeveld series, 2,500 feet or more below the basal members of the Dwyka in the Karroo district, is in favor of the former; for the Bokkeveld, Witteberg, and Dwyka series are conformable there, and the transition from the marine conditions of the first to the glacial conditions of the last, while all three formations still lay horizontal, and while deposition continued without interruption, can hardly have involved great changes of continental altitude.

There do not appear to have been any mountains during Permian time in the parts of South Africa here under consideration. The many east and west ranges along the southern border of Cape Colony had not then

been created, for the folding that produced them included the Dwyka along with the earlier rock series. The mountains of much earlier formation, indicated by the deformation of the Pretoria (Potchetstroom) system in the Transvaal, had, as already shown, been nearly obliterated before Dwyka time opened. Not only so; the subdued remains of these earlier mountains had been extensively covered with the barren Waterberg sandstones (the supposed northern equivalent of the Table Mountain sandstones) in the northern Transvaal before Dwyka time opened, and the horizontal attitude still, as a rule, preserved by the Waterberg series north of the Dwyka area (see Hatch and Corstorphine, pages 180-182), demonstrates that no renewal of mountain-making deformation had taken place in that neighborhood—the apparent source of the Dwyka ice—before the ice-sheet was formed. The observations of Bornhardt (460) in German East Africa and of Passarge (594) in the Kalahari point to the same conclusion. Uplifted areas there must have been, however, somewhere in South Africa then or soon afterward, in order to provide the great bodies of sediment deposited in the heavy Karroo series.

CLIMATIC CONDITIONS OF DWYKA TIME

Change of temperature.—If it has been correctly inferred that the Dwyka area and the area next north of it was a region of moderate altitude and on the whole of moderate relief in Dwyka time, and that it occupied then, as now, a latitude only a few degrees outside of the torrid zone, it follows that the cause of the Dwyka ice-sheet must be searched for in a general lowering of terrestrial temperatures. In no other way can a sufficient snowy precipitation on a lowland in latitude 25 degrees be produced. The reasons that lead to this conclusion are as follows.

The Dwyka area today occupies the outer part of the southern trade wind belt. It is not reached by the winter rains of the southern subtropical belt, which do not extend farther than the southern coastal border of Cape Colony. The interior receives its rainfall chiefly from disturbances in the trade wind belt during the summer season. The winters there are prevailingly clear and dry, because of the presence of a seasonal area of high pressure, shown in Bartholemew's Meteorological Atlas as a part of the southern belt of high pressure that encircles the world, intensified over the land areas in the colder season. This is an extremely important point in connection with the study of Permian climatic conditions, for it shows that the dryness of the winters and the rains of the summers are inseparably associated with persistent elements of the terrestrial wind system. There appears to be no means of modifying this ar-

rangement of the seasonal rainfall, so long as the zones have their present positions; and herein lies one of the most peculiar as well as one of the most difficult elements of the Dwyka problem. The Pleistocene ice-sheets of northeastern America and northwestern Europe are sufficiently explained by a moderate intensification of the present winters. Recent studies of Alpine glaciation show that it can be accounted for by a lowering of the snowline such as would result from a reduction of the mean annual temperature by a few degrees centigrade. The Dwyka glaciation is peculiar in that an intensification of its winter climate would leave its area free from ice. It is the summers of the Dwyka area that must be made wintry before an ice-sheet can be provided; and then a still colder winter, dry and clear, would intervene between the snowy summers. This may perhaps be made plainer by considering in some detail various possible changes of factors which affect climate, such as land area, land form, ocean currents, and seasonal migration of the wind belts, in order to determine whether any other change than general refrigeration would effect the desired result. It should be remembered that under the last of the headings here named it is not admissible to shift the various belts of the terrestrial wind system arbitrarily, for they are known to be intimately dependent on the path of the equator and on the position of the poles. It is no more reasonable to postulate an arbitrary change in the position of subtropical belts by which the winter rains are furnished to the southern coastal border of Cape Colony than arbitrarily to tilt the axis of the earth into a new geographical position. The question is, then, to learn whether any change in the lands, currents, or winds, independent of changes in the intensity of insolation or in the composition of the atmosphere, would produce snowfall in the Dwyka area.

Changes of land area and form.—If South Africa had been somewhat larger in Permian time, the trade winds would have been all the better established; for the greater the area of an equatorial continent the higher the temperature of its equatorial belt and the stronger the indraft of the trade winds. On the other hand, the larger the land area of a trade wind region, the drier it will be, provided its altitude is low. There would probably, however, be an increased migration of the heat equator on an enlarged continent; but this could only bring warm summer rains toward the Dwyka area. It is quite possible that, if equatorial Africa were submerged while South Africa were enlarged, extensive monsoons would be established and the equatorial rains might be carried 20 or 30 degrees south of the equator, for they are carried some such distance north of the equator in India; but, in order that snow should be gathered under the south-shifting equatorial cloud belt with the present distribution of mean

temperatures, nothing less than a lofty mountain range, like the Himalaya, would suffice; and even then it would be impossible to produce an ice-sheet on the polar side of the range. Indeed, under existing conditions as to mean annual temperatures, no imaginable mountain range in latitude 25 degrees south could gather snowfall of sufficient amount to form on its polar side a piedmont ice-sheet that would move 600 miles across a lower land to latitude 33 or 34 degrees. A heavy snowfall on the polar side of such a mountain range could be supplied only by the trade winds, which would ascend the poleward mountain slope; but the heavy rains that such winds would give forth at moderate altitudes, before their temperature was reduced to the freezing point, would effectually melt the ice that might descend from the higher levels at which snow would be formed. There is little assistance gained by postulating great highlands for the entire Dwyka area; for, apart from the strong improbability of their occurrence, as already indicated, the precipitation on them in trade wind latitudes would take place chiefly around their bordering slopes, while the highland areas would be left comparatively dry, even though they were cold. Changes of land area or land form therefore appear to be ineffectual in producing a glacial climate in subtropical South Africa.

Ocean currents.—No conceivable arrangement of continents and ocean currents could produce an abundant snowfall in latitude 25 degrees, so long as the general temperature of the atmosphere preserved its present values. Even if both Permian Africa and Permian Australia reached farther south than present South America and diverted toward the equator a greater body of colder water than now flows equatorward in the Peruvian or Humboldt current, such currents would not alone cause the trade winds to precipitate snow over a lowland in latitude 25 degrees. It must be remembered that, however cold the poles, the ocean currents moving toward the equator could not be colder than 28 or 30 degrees Fahrenheit at their source, and that they must under existing conditions as to sunshine rise in temperature 30 or more degrees on their way to the equator. So far as a cold current in the Atlantic west of Permian Africa is concerned, its effect on the trade wind belt of southeastern Africa would be practically nothing, because the current would be far down the wind, or to leeward. So far as a cold current in the Indian ocean west of Australia is concerned, it would have gained a temperature of at least 60 degrees, more likely 70 degrees, on reaching the equator; it would be warmed to a somewhat higher temperature as it flowed westward along the equator, and it therefore could not produce a very low temperature when returning poleward along the east side of Africa. A

cold current running equatorward along the east coast of Permian Africa in lower latitudes than 40 degrees is hardly conceivable. It may be barely possible that such a current existed in Permian times, but it has no analogue in the present arrangement of ocean currents.

The subtropical belt.—The occurrence at present of winter droughts and summer rains over the Dwyka area is so unfavorable a condition for glaciation that it is necessary to inquire whether winter precipitation might occur there under any admissible conditions. The only reasonable scheme for producing such a result involves an increased migration of the subtropical belt, such as may be brought about by increasing the contrast of equatorial and polar temperatures in the winter hemisphere. There are two unlike conditions from which such an increased contrast might follow: One involves a persistently greater warming of the equator by sunshine or a greater cooling of the poles by radiation. As a consequence, the general circulation would be strengthened all the year round, and the subtropical belt in the winter hemisphere would be driven farther toward the equator; and in this way the winter precipitation, which now reaches only the southern extremity of Africa, might advance over the interior. Yet even under extreme conditions of this kind it is doubtful whether the subtropical belt could be thus driven ten degrees of latitude nearer the equator than it now reaches; and furthermore it is manifest that, if it were so driven, there would still be the warmth of summer and its rainy precipitation to melt the winter snows; hence it is not likely that effective assistance in the production of the Dwyka ice-sheet can be thus afforded.

The second possible condition involves an increased eccentricity of the earth's orbit, with the southern winter in aphelion. An increased contrast between equatorial and south polar temperatures in winter would then be brought about by a fall in the temperature of the Antarctic regions. The general circumpolar circulation of the atmosphere in the southern hemisphere would consequently be strengthened during the long severe winter, the subtropical belt would be thereby driven farther toward the equator, and the precipitation from it would be more largely in the form of snow than it is at present. It is difficult to believe, however, that a change of this kind would suffice to produce enough snow in latitude 25 degrees for the formation of an extensive ice-sheet, unless a decided reduction of mean annual temperature accompanied it. It may be pointed out that the aphelion winter theory involves a contemporaneous mild winter in the northern hemisphere; it is therefore to that extent inconsistent with the supposed equivalence of the Dwyka glacial formation with the Talchir glacial formation of northwestern India.

General refrigeration.—Refrigeration alone—either by a decrease of solar radiation or by a change in the constitution of our atmosphere—without any significant shifting of the wind belts, would have to be extreme in order to produce an ice-sheet in latitude 25 degrees; for it would be necessary in such a case to reduce the summer temperature of South Africa so that the summer rains should be changed to summer snows, the winters remaining dry, but becoming extremely cold. Such a refrigeration would freeze up all the temperate lands; and there does yet appear to be sufficient reason for supposing that so general a Permian refrigeration has taken place. A special study of the Permian formations of the whole world in this connection would be instructive.

Shifting of the poles.—An altogether different explanation for the climate of the Dwyka ice-sheet is found in the frequently suggested change in the attitude of the earth's axis, so that the poles with their normally low temperatures might be placed nearer the present position of the equator. It is well known that a change of the north pole to a position near Iceland would favor the production of the Pleistocene ice-sheets in northeastern America and northwestern Europe; for it would not only decrease the mean annual temperature of the glaciated areas, but it would, by setting the equator in the Atlantic south of cape San Roque, prevent the deflection of a large body of warmed water from the South Atlantic to the North Atlantic, and thus decrease the volume of abnormally warm water which now, under the popular but inappropriate name of the Gulf stream, flows past Norway.

If a change in the position of the axis took place in Permian time, it would seem easy thus to account not only for the Dwyka glacial formation of South Africa, but also for the Talchir glacial formation of northwestern India, and for the Muree glacial formation of southeastern Australia, as various geologists have pointed out. It should be recalled that, in favor of the hypothesis, the movement of the Talchir ice-sheet in India was, like that of the Dwyka ice-sheet in South Africa, *away* from the equator. But there are various embarrassments connected with the acceptance of this daring hypothesis. There is no efficient cause known by which so great a change in the position of the earth's axis as is here needed can be accounted for; there appears to be a less frequent occurrence and a smaller extension of glacial formations in the whole geological series than one might fairly expect there would be if the earth's axis were in the habit of varying its position; and there are so many areas of undisturbed Paleozoic strata that it is unreasonable to admit the occurrence in later time of the various deformations of the earth's crust that might have to follow a shift in the location of the equatorial bulge

and of the polar flattening. The shifting of the poles is therefore at present not only a daring hypothesis, but gratuitous and discredited as well. Nevertheless, if evidence of Permian warm climate were found around a zone that would be equatorial to an Indian Ocean polar area, and if another Permian glacial area were found in the regions antipodal to the Indian ocean, this daring, gratuitous, and discredited hypothesis would have to be taken seriously into account.

The cause of the Dwyka glaciation for the present remains a puzzle, although the fact of the glaciation is well established.

THE INTERIOR HIGHLAND: THE VELD*

THE SCHEME OF THE GEOGRAPHICAL CYCLE

Our rapid journey inland from Cape Town as far as Johannesburg and Victoria falls, and then eastward to Beira on the Portuguese coast, gave a particular pleasure to some of the geographically minded members of the party, who attempted to refer the various land forms that were seen to their appropriate place in the scheme of the geographical cycle. This scheme recognizes that if the ordinary processes of erosion carry on their destructive work without interference by crustal movement or by climatic change for an indefinitely long time, they will eventually wear down any land area, whatever height and form it originally had as a result of uplifting forces, to a nearly featureless lowland, hardly above sealevel. On such a lowland plain the further processes of erosion must be very slow; the rivers would have long since reduced their courses to gentle grade, with extremely faint declivity toward their mouths in the sea; the branch streams would have given up the torrential activity of their youth and become sluggish tributaries in their old age; and the smaller rills would have been largely extinguished by lack of ground-water discharge in springs on the flattened land slopes, for the hills that rose between the eroded valleys during the stage of vigorous maturity would by this time have been worn down to faint swells, seeming almost level to the eye, and the ground-water would find few points of emergence until the larger channels were reached. The waste of the land, prevailingly of fine texture, would be slowly washed down the nearly imperceptible slope of the swells toward the streams, and carried by the streams and rivers along their well ordered courses to the sea. The watercourses would not follow

*This section of the present article is expanded from the notes of an informal address given on the deck of the steamer *Durham Castle* during the return voyage of the British Association party from Beira, by the east coast of Africa, to Southampton, September-October, 1905.

valleys in the ordinary sense of that term, but would lie in the broad surface of faint depressions between equally faint swells: there would be no hills, no escarpments, no terraces. The agencies of transportation would have come to be so nicely fitted to their work that the streams would be everywhere competent to sweep along the load of waste supplied to them by the weathering agencies; the soils might be deeper in one kind of rock or shallower in another kind, but there would be no heavy accumulations of transported soil; alluvial deposits would occur only in relatively narrow and shallow belts along the stream courses.

Now a land form of this kind is seldom found; it is a geographical rarity. Plains are common enough, but plains such as those of northern India or western Turkestan are not the work of erosion, but of deposition, and should not be confounded with plains of erosion, just described. Some geographers have indeed urged that the crust of the earth has not anywhere stood still long enough for the production of a plain of erosion; hence all the more interest would attach to such a plain if it were found.

THE OPEN VELD A PLAIN OF EROSION

Before leaving Cape Town we were told that the scenery along the railway line on the interior highland or Veld to Johannesburg was monotonous and uninteresting. I made that journey in the sympathetic company of Professors Penck, of Vienna, and Coleman, of Toronto, when we were hurrying from the geological excursion in the Karroo with Mr Rogers to another excursion in Vryheit with Messrs Anderson and Molengraaff; and seldom has a railway journey proved more entertaining than the daylight run we made over the Veld from De Aar to Bloemfontein, for we crossed miles and miles of plains that repeated in nearly every respect the features of the ideal worn-down land surface, such as belongs in the latter part of the physiographic cycle of land forms. This profitable experience was repeated on the return from Johannesburg around to Kimberley, when we saw in the morning a stretch of the Veld north of Bloemfontein that had been crossed at night on our way up country. I will first point out the elements in which the actual features of this region support the scheme of the cycle, then mention some special features, and finally ask attention to some problematic matters concerning which a much more extended study of South Africa must be made than that which was possible in our short excursion.

There are many stretches of Veld—open, treeless, unfenced country, hundreds or thousands of square miles in area and several thousand feet above sealevel—that would be called level plains even by a rather careful observer; but they are not precisely level, as a view back or forward along

the railway line soon shows. The surface has broad swells of very faint convexity between broad depressions of equally faint concavity, and it may therefore be called a peneplain instead of a plain, as if it represented the penultimate and not the ultimate stage of the geographical cycle. The Veld is not a surface of accumulation or of construction; it is a surface of erosion, for the various formations of the Karroo system of which the region is built up are often seen under the thin soil, obliquely beveled by the gently undulating plain. Moreover, the Veld is frequently surmounted in one district or another with ridges and tables of resistant dolerite, whose occurrence demands the former presence of higher Karroo beds to an additional thickness of hundreds or thousands of feet. Again, certain parts of the Veld are not reduced to so small a relief as those just referred to, and hence seem to show a less advanced stage of development; here the more distinct swells and troughs are called *bults* and *vleis* by the Boers.

It should not be understood, however, that in considering the highland of the Veld as a peneplain it is intended to imply that it stands at one level over its great extent. A peneplain must have a perceptible measure of residual relief; its streams must exhibit a gentle slope, and hence, when its surface extends over hundreds or thousands of miles, it is essential that its different parts should be of different altitudes. Just what the existing differences of altitude amount to it will be impossible to say until the region is surveyed. It is evident that the openness and prevailing smoothness of the Veld has favored the advance of settlement across it.

It is especially noteworthy that the faint depressions of the Veld are as a rule not undrained hollows (we saw few "pans" on our journey), but are arranged in branchwork fashion, systematically joining one another downstream in a way that can be explained only by long-continued river work; the faint depressions are indeed nothing more nor less than valleys in their old age, although they are as unlike the steep-sided troughs which the term valley ordinarily suggests as the faint swells of a worn down range are unlike the mountains from which they have been reduced. This old drainage system seems thoroughly organized, although not very energetic, all its parts being closely interdependent and everywhere showing that wonderfully delicate adjustment of declivities which brings the graded lines of interstream slopes into accordant junction with the stream courses, and the stream courses with each other. On the surface thus fashioned the drainage system seems, precisely as the theory of the cycle leads one to expect, everywhere just competent to do its duty—that is, to carry along the waste that is washed from the broad surface of the faint

swells to the streams and along the streams to the rivers. Not only the stream courses, but the general surface of the plain, is and has long been reduced to grade. The delicacy of drainage organization here involved is worthy of close attention; it can be explained only by the long undisturbed and continued action of erosive agencies, and its attainment may therefore be taken, along with other features above mentioned, as evidence that the region of the Veld has really been undisturbed by crustal movement through a long period of time, and that it is actually a plain of long continued erosion. It is distinctly not a dissected peneplain in the areas here considered; the streams do not flow in narrow valleys that are eroded beneath the level of the peneplain, as is so often the case in other parts of the world, but flow in mere channels through the very shallow and very wide open valleys appropriate to old age.

The absence of rill channels on the slopes of the faint swells is a characteristic peculiarity of the Veld very appropriate to old age. This feature is probably to be explained, in so far as a peneplain in a normal climate is concerned, by the failure of the gently sloping surface of the residual swells to intersect the ground-water surface, and hence by the failure to develop springs and small streams, as already suggested. In the case of the Veld, the absence of rills is also favored by the dryness of the climate. If contour lines were drawn on a good map of the district, they would, in the absence of rill channels, sweep around the swells in large curves; the many reentrant angles by which contour lines indicate the repeated divarication of streams and rills in a surface of stronger relief would here be wanting. The very broad convexity of the faintly arched swells is another matter of interest in showing how far the sharp ridged divides, appropriate to the action of streams in an early stage of the cycle, are now replaced by flat and broadly rounded divides on which normal stream action is replaced by some other process—probably wet weather wash rather than soil creep—which becomes dominant in the late stages of the cycle. It should be noted that the flat divides swell from 30 to 100 feet above the pale valleys, and from this it may be fairly inferred that peneplanation here can not be due to the lateral swinging of streams, but simply to the general wasting and washing processes of subaerial degradation. The few "pans" or undrained depressions that I saw seemed to be distinct departures from the rule of normal degradation that obtains so widely in the Veld, as will be more fully stated below.

EFFECTS OF THE DRY CLIMATE

Some of the more special features of the Veld, considered as a peneplain, may now be mentioned, and, first, certain features associated with

the dryness of its climate. The region has a pronounced dry season through the months when the sun is north, and a considerable rainfall, some thirty inches, when the sun is south; and much of the rain falls in heavy showers. The climate can not therefore be properly described as arid; yet arboreal vegetation is wanting, and even the smaller plant forms are rather sparsely scattered, leaving much bare ground between them in the dry season of our visit. The soil is probably more fully plant covered after the summer rains have begun; nevertheless the aspect of the region is distinctly that of a dry country. The processes of weathering seem to be not so much those of deep penetrating decomposition of the chemical kind as those of shallow disintegration of the mechanical kind. The processes of transportation are inactive in the dry season, but they must work very effectively in the wet season, especially during and immediately after the occasional downpours of rain that seem to be characteristic of the region. At such times the smooth slopes of the unchanneled swells must be swept by sheetfloods and the stream channels must be filled to overflowing. The sheetflood would be greatly impeded if the Veld supported a forest with thick undergrowth. The sheetflood is, on the other hand, greatly favored by the actual scantiness of vegetation, and it can hardly be doubted that erosion at this stage of the cycle progresses much more rapidly in this comparatively dry region than it would under a climate moist enough to support an abundant cover of vegetation. It must be chiefly by the action of the efficient sheetflood that the broad and gentle swells have been and are still worn down without the formation of rill channels and gullies. Residents in the region told us that sweeping floods on the plains, far outside of the stream channels, were of not uncommon occurrence from year to year.

RIVER VALLEYS AND RIVER CHANNELS

The unchanneled swells of the Veld are so broad that well defined stream channels are few and far between. This is partly a feature of old age, partly of dry climate, as stated above. At the time of our visit such channels as occur were nearly or quite dry, and we had a chance of seeing the banks and beds, which in a moister climate are usually hidden under water. The banks were largely built of fine alluvium, from 10 to 30 feet in height, and rock in place was visible in them here and there. The beds were mostly covered with silt, sand, and gravel, but sills of rock were not rare. The railway usually crossed the larger channels where rock sills occurred, in order to have good foundations for the abutments and piers of its bridges. The channels were sometimes so deep that they had the appearance of young valleys, new cut beneath the plain, as if by the re-

juvenation of the streams, and so they were at first interpreted; but I am persuaded that such was not the case. The depth of the channels was merely a sign of the great fluctuations of stream volume in a region where heavy rains are chiefly discharged by rapid run-off from an open surface. The rock sills in the channel beds sometimes determined the site of little rapids or low cascades in the trickling streamlets that alone represented the rivers in the dry season. This also at first sight suggested a recent rejuvenation of the old drainage system; for rapids and falls are always to be associated with young rivers, while old rivers are supposed to be normally of gentle and even grade, without any trace of local hurry in cascades, all of which should have been obliterated in the earlier stages of the cycle. But in this case, as in the other, further consideration shows that the little rapids of the low-water streamlets are not at all inconsistent with normal old age; for when the channels are occupied by the flooded rivers the small unevenness of the channel bed can have no significant effect in disturbing the even slope of the river surface. The smoothness of the floodplain confirms this; it is without perceptible inequality of slope and shows no change of level where low rock sills occur in the channel bed below. It is therefore the high-water river and the floodplain associated with it which should be taken to represent the normal features of old age; the low-water stage is an abnormal condition of a river, and gives less evident indication of the stage of its development.

STORM-FLOOD CHANNELS

Some of the wide open, old valley floors were dissected here and there by branching channels cut in the alluvium to a depth of 10 or 20 feet; and this led us to question whether a slight disturbance in the normal progress of events had not taken place. For example, after a time of more thorough erosion, a climatic change might have occurred during which a deposit of alluvium would accumulate, and this in turn might have lately been followed by a period of more active erosion whereby the accumulated alluvium would be channeled. On the other hand, it seems possible that the occasional heavy downpours which are characteristic of the rainfall on the Veld may sometimes flood the streams into so violent an activity that they cut deep channels in the alluvium that has been accumulating in the long intervals of less rainfall, and thus the master flood of the century may make a record which is very striking if of recent occurrence, but which is gradually lost as the deep cut channels are silted up. In this case the rock floor beneath the alluvium will be worn down only when and where the deep cut channels are ripped open

by the master floods—a slow process truly, but not slower than the penultimate erosion of a land surface should be. It may be added that we saw in the Vryheit district of Natal many gulches in hillside alluvium, which were explained as storm-flood channels by Mr Anderson, who there accompanied us. I am tempted to think that the occasional branching channels in the alluvium on the Veld are best explained in the same way.

Some of the railway cuttings near Johannesburg exhibited a succession of soil and rock fragments which seemed abnormal and which may come to be interpreted as indicating a change of climate; this is merely put on record here, but not discussed, as it was only seen from the passing trains.

UNDRAINED HOLLOWS OR "PANS"

There are certain parts of the Veld in which shallow undrained depressions or "pans" occur, often holding lakes or pools of variable area. Not many of these were seen from our route of travel, and we were not able to give special attention to the few which we passed. No satisfactory explanation for the depressions has been offered. The underlying formations are not known to contain soluble minerals whose removal might cause a settling of the surface. The action of the wind may perhaps be appealed to, for the scanty vegetation of the Veld permits the wind to reach a large part of the surface of the ground, particularly in the dry season, but I am not aware of any special features of the pans which demonstrate their origin by wind action. The long continued removal of a significant amount of fine soil during each wet season by animals has been suggested, and when the large numbers of antelopes that formerly roamed here is considered, this suggestion seems to be not without value. But important as the pans are in certain districts, the action of surface wash and sheetfloods seems to be dominant over the greater part of the Veld, for the surface very generally exhibits that systematic arrangement of drainage lines and slopes which long continued washing must produce and which long continued wind action must destroy. Further reference to this matter is made in the closing section of this article.

RIDGES AND TABLES OF DOLERITE

We may next consider the effects of variation of rock structure in causing variations of form in the Veld. In the ideally simple scheme of the geographical cycle a land mass of uniform structure is usually postulated, because in such a case the action of the erosive processes is not complicated by the unlike resistance of strong and weak rocks. This simple

condition is almost realized where the Veld is underlaid by stratified rocks, but it has been already stated that doleritic intrusions in dikes and sheets are not uncommon. Where these resistant rocks occur it is but natural that they should stand up in much more mature relief than that of the old plains which have been worn down around them on the weaker rocks. It is evident enough that if the whole region consisted of resistant dolerite the surface would not now be worn as smooth as it is in the actual areas of the weaker stratified rocks; for the time and the agencies that have sufficed for the peneplanation of the latter would have hardly carried the former beyond maturity. From what we could learn, it seems probable that the Stormberg mountains, which rise along the southeastern border of the Veld, are an example of such a more resistant district; their structure seems to be essentially horizontal, and they are said to contain much dolerite. They may therefore be provisionally looked upon as representing in their height and form something of the maturity through which the weaker rocks of the Veld have long since passed.

The side slopes of the ridges and mesas formed on the dolerite dikes and sheets are suggestive of the slow erosive processes by which the ridges are being slowly worn down. The crests and the steeper part of the upper slopes consist chiefly of bare dolerite. There the agencies of removal are somewhat in excess of the agencies of disintegration; rock fragments are rolled down as soon as they are detached from the parent ledges. Farther down, where the slope is less steep, it is covered with coarse waste or talus from the bare ledges above. Here the agencies of removal are only able to carry away the middle textured and finer waste that comes partly from the disintegration of the coarse waste and partly from the disintegration of the underlying rock. The talus-covered slope turns by a rather short curve into the plain, where the soil is of relatively fine texture. Here the agencies of removal are able to carry away only the fine waste that comes from the relatively complete disintegration of the materials farther uphill and of the underlying strata. Thus the talus slope as well as the plain is essentially at grade with respect to the agencies and materials there concerned, though the slopes of the two are very different; but the top of the ridge is not yet reduced to grade. The front view of the ridges gives one the impression that the talus slope and the plain meet at an angle; the profile view shows that the two surfaces are connected by a short curve, as already stated, and close inspection shows that the plain near the base of a ridge has a slightly greater declivity and a slightly coarser waste cover than farther forward. It sometimes happens that the stratified rocks may be seen through the talus slopes, especially on the slopes of

dolerite-capped mesas, and from this it must be understood that the talus is not a thick accumulation, like the heavy fans that accumulate at the base of oversteepened cliffs in glaciated districts; it is only a sheet of waste whose fragments travel slowly down the slope, while the slope slowly retreats before the slow expansion of the plain at its foot. The talus slopes are seldom ravined, and from this it may be inferred that the talus, like the plain, is acted upon rather uniformly over large areas instead of on lines of concentrated water flow. We saw indications at various points that the contrast of conditions between ridge and plain acted as a control in the distribution of vegetation, concerning which the botanists of the party could probably give details. It would appear also that the stony slopes of the ridges and mesas might often serve to harbor various forms of animal life which could find no satisfactory refuge on the featureless plains. But it sometimes happens that a broad sheet of dolerite lies at a level only slightly above that of the surrounding plain, and in such case the flat surface of the sheet is covered with boulders of decomposition to such an extent as to exceed in this respect the talus slopes of the ridges and mesas.

RELATION OF RIVERS AND RIDGES

The relations of the drainage system to the dike ridges present some interesting features. The plains may be conceived as more or less completely divided into irregular compartments, large and small, by the ridges. Many of the compartments are drained by streams that escape where the ridges are wanting; the plains of such imperfectly separated compartments form a continuous surface of uninterrupted grade; but it not infrequently happens that the stream by which a compartment of the plain is drained enters the compartment or escapes from it through a notch in one of the inclosing ridges. Then the plains up and down stream from the notch are not at precisely accordant levels; for the stream in the notch is usually of a steeper slope, either on bed-rock or on large boulders, than it is on the open plains. The plain upstream from a notch is of course graded with respect to the notch; the plain below the notch is graded with reference to some other local baselevel farther downstream. This relation has probably obtained for ages past, the graded plains having been worn down as fast as their local baselevels were lowered. Here as elsewhere the highly developed organization of the drainage system is exhibited. There is, for example, no excessive accumulation of alluvium on a plain upstream from the notches which are so characteristic of the region; hence there does not seem to have been either an undue deepen-

ing of the plain above the notch, followed by aggradation, or an undue supply of waste in excess of that which could be carried through the notch. The plains and the ridges, the stream channels and the notches, are essentially such as one might expect to occur in the undisturbed old age of a region of hard and soft rocks in a subarid climate, and hence we are warranted in supposing that erosion has been steadily in progress on the Veld for a long time in the past. However the river courses were originally determined, they must have been running practically on their present courses during at least the greater part of the period in which the later erosion of the plains has been accomplished, and during that period South Africa appears to have been an undisturbed land area.

PENEPLAINS IN OTHER PARTS OF SOUTH AFRICA

The condition of long enduring continental quietude indicated by the peneplanation of the Veld appears to have obtained in other parts of South Africa as well. On our way northward from Mafeking we passed through a granitic district on the eastern border of the Kalahari where the general relief was small and where the watercourses were slightly, if at all, incised in the broad and shallow depressions that sank beneath the broad and gentle swells, as on the Veld. Occasional knobs and mountains—"Inselberge," as they have been called by German explorers—rose above the plain. Farther north, around Bulawayo, the steeply inclined schists are truncated in a broad, gently undulating plain; but here the watercourses were rather more distinctly incised than in the other districts named. Not far from Bulawayo is a group of granitic hills, known as the Matopos and famous as holding the grave of Cecil Rhodes at the summit of one of their higher eminences; they are monadnocks of granite that rise above the surrounding peneplain of schists. A small example is shown in plate 49, figure 2. Again, on approaching Salisbury, the capital of Rhodesia, we crossed a gently undulating plain eroded on inclined rocks and interrupted by a pronounced ridge of nearly vertical strata, apparently quartzites, through which the railway passed in a sharp notch. East of Salisbury the undulating plain seemed to be worn down on granite, which often rose in local knobs and heaps of weathered boulders like small Matopos. We were told that the railway line from Bulawayo to Salisbury was laid nearly along the water-parting between the Zambesi and the Limpopo, so as to avoid the valleys of the larger branches, which are more and more deeply incised beneath the highland as the main rivers are approached.

The reports of two explorers may be cited to show the existence of extensive peneplains farther north and northwest. For example, Born-

hardt (27-29)* describes the uplands between Lake Nyassa and the eastern coast as consisting of gneiss, generally reduced to a surface of small relief, but here and there surmounted by residual eminences, or Inselberge. Passarge (*a,* 636-638) says the same of large areas of the Kalahari Desert area.

The various peneplains here referred to can not at present be surely correlated as belonging to the same cycle of erosion, but there is a presumption that they are of similar dates of development, and they certainly all agree in testifying to the quietude of the continent for a long time and over a large area.

DISTRICTS OF STRONGER RELIEF

Although a great part of the South African highland may be described as made up of undulating plains and accounted for as the result of long continued, penultimate erosion, there are certain districts where the relief is hilly or submountainous. The Stormbergen, for example, which lay southeast of our route across the Veld, are several thousand feet higher than the highland. They are built of the youngest members of the Karroo system, reinforced by abundant sheets of dolerite. They are believed to be residual eminences that have survived the erosion which has swept away the less fortified strata elsewhere. In the neighborhood of Pretoria there are several well defined ridges, the greatly denuded edges of various resistant formations belonging to older geological systems than the Karroo. The famous Rand or escarpment at Johannesburg is another example of the same kind. The moderate relief to which these ridges are reduced from the former much greater extension of their strata is the result largely of pre-Karroo erosion, partly of post-Karroo erosion. North of Kimberley we saw a long even-crested escarpment in the distance to the west of the Vaal river. North of Mafeking the railway passed among a number of subdued mountains believed to be composed of the same formations as those about Pretoria, as shown on the valuable geological map of the Transvaal, by F. H. Hatch, in Hatch and Corstorphine's Geology of South Africa. The Inselberge on the eastern border of the Kalahari and the Matopos near Bulawayo have already been mentioned.

* The explanation that Bornhardt here offers for the even surface of the upland which he describes does not seem satisfactory. He supposes that the region concerned, once surmounted by additional rock masses and therefore rising to a greater altitude, was dissected to maturity and then depressed and buried under later sediments and again elevated; and that by several repetitions of this process a number of independent criss-crossing valley systems were developed. so that their confluent floors would form a plain, while the intermediate spaces were left rising in isolated knobs. The difficulty here is that in the successive periods of elevation and erosion there is no guarantee that the land mass shall resume the same altitude, and hence no reason for thinking that the space between the knobs should be reduced to a single plain.

On the way to Victoria falls the country was rougher than any other district that we traversed on the highland, but all the mountains and hills thereabout seemed to be merely residual eminences of harder rock, like the dolerite ridges and mesas of the Veld. Their survival in no way contradicts the explanation of the Veld by long continued and more effectual erosion.

The east and west ranges which occupy the southern part of Cape Colony are not mentioned in the preceding paragraph because the broad valleys between them are lower than the highlands of the Veld. These ranges should probably be associated with the mountains and escarpments which roughen the slope where the highlands descend eastward to the Indian ocean, for I gained the impression that in both these areas, south and east of the Veld, the peneplain of the highland had once extended farther toward the sea and had afterward been dissected by short rivers of rapid fall.

OCCASIONAL DEEP VALLEYS

A notable feature of all the high standing peneplaned areas that we traversed is their comparative freedom from deeply incised valleys. High standing peneplains are common in many other parts of the world, but they are, with hardly an exception, more or less completely dissected by the rivers that drain them. In South Africa undissected continuity seemed to be the rule and dissection the exception. The rivers flow, one may almost say, on the plain. The only striking example of dissection that we saw within the plateau area was the gorge of the Zambesi below Victoria falls. Here the river has cut down its extraordinary zigzag trench beneath the floor of a very broad and shallow preexistent valley. It may well be, however, that on account of our journey having been so largely by rail, and on account of the railways having been located as far as possible along the broad highland divides between the larger and deeper valleys, as between Bulawayo and Salisbury, that we gained an undue impression of the freedom of the highland from dissection; yet where we crossed the Orange and the Vaal rivers and their branches the valleys were very little, if at all, sunk below the level of the adjoining plains. It should be remembered, however, that the Orange river is described as having falls in its lower course, west of the Veld, and it is to be presumed that these falls are associated with a more or less distinctly entrenched valley. Special physiographic observation is much needed on this point.

VICTORIA FALLS OF THE ZAMBESI

The peculiar zigzag pattern of the "Batoka gorge" of the Zambesi river below Victoria falls has been well shown by Molyneux to depend on the ex-

istence of groups of transverse vertical joints or fissures in the horizontally bedded basalts which here build up the plateau. The course of the river near the falls is to the south-southeast. Above the falls it follows a broad, open, and shallow valley inclosed by sandy uplands which ascend gently one or two hundred feet above the river. A similar valley is easily seen to continue below the falls, but there its floor is cut by the zigzag gorge. The gradual widening of the main gorge and the increased length of the lateral gorges farther and farther downstream, as described by Lamplugh, leave no doubt of the normal origin of the gorge by river erosion.

The falls at present stretch across the whole breadth of the upper river. The waters plunge down from a rather straight wall-like face of rock into a deep transverse cleft that has been worn out on one of the groups of transverse joints and fissures. The cleft is soon followed by a transverse wall of more solid rock, through which a narrow passage leads the river to the next transverse cleft, and so on down the gorge. Above the falls transverse belts of smoother and deeper water interrupt the rippling belts of shallower water at intervals of a few hundred feet. These deeper belts probably indicate as many groups of joints and fissures and appear to be the embryonic form of future transverse clefts separated by more solid walls. Several local channels are forming across the wall from which the falls now plunge. At times of lowest water the less worn top of the wall may be partly dry, nearly all of the water being then gathered in the local channels. At times of high water the great flood carries deep water from bank to bank, and spray and foam then rise from the cleft in such volume as almost to hide the falls. As time passes, one or another of the local channels will be cut deeper and deeper, until it takes all the water from the next upstream deeper transverse belt. The local channel then becomes a connecting passage, the deeper belt is worn down to a deep transverse cleft, to whose upstream side the falls are shifted, and the wall of the present falls is left standing high and dry. It has been by essentially a series of such changes that the existing zigzag gorge below the falls has been eroded. The transverse clefts are subparallel, but the location of the connecting passages is a matter of chance, as it depends on the success of one local channel in being worn down a little faster than another; hence the peculiar zigzag course of the narrow river below the falls, in contrast to the relatively direct course of the broad river above the falls. The connecting passage that now leads the waters from the falls cleft through the next transverse wall is about a fourth way from the eastern to the western end of the wall. The passage that cuts through the second wall below the falls is at its western end; it is around

this wall end that the river makes its extraordinary turn in front of the hotel and railway station, close by on the southern upland—a view that is often shown in photographs. A connecting channel appears to be at present in formation close to the western end of the present falls. It thus appears that the explanation offered by Molyneux not only accounts for the peculiar pattern of the gorge already formed, but suffices also to show that the peculiar process of its formation is still in progress, and that the future gorge will be, for some time at least, as remarkably zigzag as the present gorge. It is noteworthy that the whole depth of the gorge is cut in resistant sheets of basalt: there is in this case no question of a hard capping layer on a weaker underlying mass, such as commonly determines the occurrence of waterfalls in dissected plateaus.

THE EASTERN ESCARPMENT

When the eastern border of the highland is reached it is found that the headwaters of many streams which flow rapidly down to the Indian ocean are retrogressively gnawing into the plateau and dissecting its edge. The best example of this kind that came to my notice was on the railway line from Durban to Johannesburg, between Charlestown (Natal) and Volksrust (Transvaal). Here a headwater stream of Buffalo river, which flows southeastward and joins the Tugela on the way to the Indian ocean, occupies a narrow valley, sharply incised beneath the rolling uplands, over which rise in turn the more resistant rocks in ridges and mesas; of these Majuba hill, on the general line of water-parting between the east-flowing and west-flowing streams, is one. The head branches of the Vaal in this district occupy shallow, wide open valleys. It may be noted that the upper Buffalo river receives Berlang river, a stream about 30 miles long, from the east, very much as if the latter had once belonged to the Zand-Klip-Vaal-Orange system and had been afterward captured by the Buffalo at the point where its waters turn sharply to the southeast, round an angle of over 120 degrees.

The headwaters of the east-flowing Elands-Crocodile-Komati river system in northeastern Transvaal are also deeply intrenched beneath the rolling Veld near Belfast, but the valleys are here more widely opened, as if they had longer been in possession of the area than is the case with the westernmost branch of Buffalo river near Volksrust, above mentioned. The highland that rises over the headwaters of Elands river consist of strata of the Pretoria and Karroo systems, dipping gently westward or southwestward; but the uplands maintain their generally level skyline, which bevels the gently dipping strata in a manner highly suggestive of peneplanation in a cycle of long continued erosion anterior to the present

cycle. The features just mentioned were seen during an excursion under the direction of Mr A. L. Hall, of the Transvaal Geological Survey, from Johannesburg to the Duivels Kantoor and back, by the railway line between Pretoria and Delagoa bay. The Duivels Kantoor, or Devil's shop, is a promontory in the bold escarpment by which the highlands are here terminated eastward; it lies a few miles south of the deep valley of the Elands river and is reached by a wagon road from Godwan station. From its edge one overlooks the lower land, which is elaborately dissected in deep weathered granite and in which Barberton lies. A general idea of the form of the escarpment is given in figure 11, looking southward. The determining stratum is the Black Reef quartzite, dipping gently

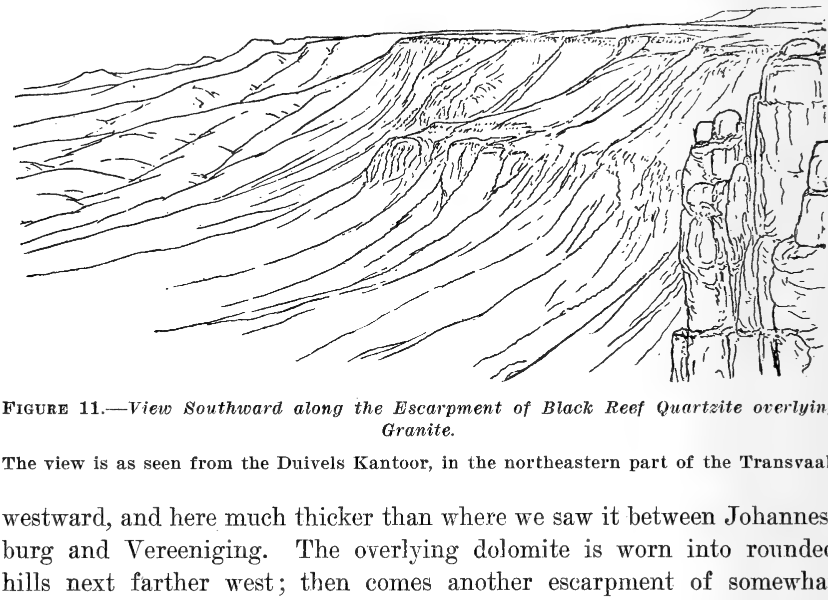

FIGURE 11.—*View Southward along the Escarpment of Black Reef Quartzite overlying Granite.*

The view is as seen from the Duivels Kantoor, in the northeastern part of the Transvaal.

westward, and here much thicker than where we saw it between Johannesburg and Vereeniging. The overlying dolomite is worn into rounded hills next farther west; then comes another escarpment of somewhat greater altitude, but of less pronounced form, determined by certain resistant quartzites of the Pretoria (or Potchefstroom) system; and thus the full altitude of the High Veld is reached. A part of this higher escarpment is shown on the right in figure 11. Where Elands river flows eastward across these west-dipping quartzites, there are two waterfalls, and here the grade of the railway is so heavy from Waterval Boven to Waterval Onden (Above the Falls to Below the Falls) that a toothed strip is added between the rails, into which a cogwheel under the engine fits. Some members of our party made frequent mention of certain supposed faults by which the descent from the interior highland to the ocean on the east is supposed to have been effected; but when the profile of the

descending slope is drawn on true scale a very gentle warping without faulting seems to satisfy all the requirements of the case.

Still farther north, where our route led from Salisbury on the highland to Beira on the coast, we saw at Umtali, on the border of Rhodesia, a late mature topography apparently eroded below the level of the Salisbury highland by rivers that have a comparatively short course to the sea. On passing Umtali we descended rapidly along the valley of a stream which flows almost directly to the coast and whose young headwaters appeared to be actively encroaching upon the broad valley floor in which Umtali lies. The features at the divide between the mature and the young valley would have afforded an admirable subject for study on the ground during our nine-hour stop there; but, as no one seemed to have taken note of them before, our time was spent chiefly in a walk to one of the neighboring hills, where we had a general view of the surrounding country, and the statement here made regarding the young headwaters is based only on what was seen from our train running fast down grade in the late afternoon.

Important as may be these several examples of marginal dissection by the rivers of Natal and the eastern slope generally, and impressive as may be the example of central dissection by the Zambesi, it remains true that the highland peneplains are still undissected over large areas, and that their streams do not usually follow valleys in the ordinary sense of that word, but flow through broad shallow depressions which represent the form assumed by valleys in their extreme old age.

ORIGIN OF THE VELD

Peneplains are normally developed as lowlands with respect to the general baselevel of the ocean surface. Such an origin may be plausibly suggested for the peneplain of the Veld. It then becomes necessary to conceive of the whole region of the South African highland as having stood, without disturbance, at a lower level than now through the geological ages required for its widespread erosion, and to imagine that it was afterward broadly elevated to its present highland altitude. In consequence of such elevation its rivers would proceed to intrench themselves beneath its highland surface; and inasmuch as their intrenchment is not yet complete, it must under this explanation be supposed that the broad uplift of the region took place at a geologically modern date.

Another explanation has, however, been lately suggested by Passarge for high-standing plains of erosion. He conceives that an extensive arid region, from which rivers do not flow to the sea, may be slowly reduced to a peneplain of small relief, or even to a plain, at an altitude entirely

independent of the general baselevel of the ocean, and that such a plain might afterward be dissected if its rivers were increased in volume by a change to a more humid climate or if a warping of the region should give it easy drainage to the sea. Passarge indeed instances the peneplain of the Kalahari, which seems to be in a general way confluent with that of the Veld, as an actual example of arid leveling—that is, of long continued erosion under arid conditions—at its present altitude. His opinions on this point are set forth in the second and third articles given under his name in the list of references at the end of this paper. I have recently presented some general considerations with respect to this problem in an article entitled "The geographical cycle in an arid climate."

If we accept Passarge's explanation, the highlands of South Africa need not be regarded as having been elevated since they were worn down to small relief; they may be interpreted as having been produced at essentially the same altitude as that in which they stand today. The dissection which they are now suffering, particularly around the margins, should not be looked upon as the result of river revival by elevation, but of river extension by change of climate, or (especially on the east) by some downward tilting or warping of the marginal region which would aid the escape of its rivers to the sea. It thus becomes an interesting problem to inquire if any critical and distinguishing features can be discovered by which the origin of the South African highland in one or the other of these two ways may be demonstrated.

There can be no question that much exploration is needed before a final demonstration of either normal baseleveling or of arid leveling can be reached. In the meantime the following suggestions are offered for consideration.

THE VELD REGARDED AS A NORMAL PENEPLAIN UPLIFTED

If the highland of the Veld be regarded as a normal peneplain, now evenly uplifted, it should possess well developed river systems, more or less fully revived in consequence of elevation, and it should be surrounded on its ocean border by a coastal plain whose marine strata would contain part of the material removed from the peneplain during its degradation. The Orange and other river systems of the Veld are therefore expectable features of the Veld, according to this theory; but the pans or undrained hollows of the Veld are against it, and the general absence of marginal marine strata proves that a broadly uniform elevation of the region did not take place. The only approach to a coastal plain is found along the part of the ocean border in Natal.

If the original low-lying peneplain were more or less uplifted by warping and faulting, so that a large central area might reach a considerable altitude, while the marginal areas might remain either quiescent or even suffer depression beneath the sea, no coastal plain of marine strata would be expected around the resulting continental border. The uplifted highland area would during and after elevation suffer dissection by its revived river systems, particularly in those marginal areas where the slope of the river courses was increased by the warping. Over the more evenly uplifted highland there might be for some time little indication of uplift in the way of stream dissection; for a number of examples of uplifted peneplains may be cited where, although more or less dissection has taken place along the middle and lower courses of the revived rivers, the upper courses still flow essentially on the upland level as if they had not yet received any intimation of revival. Nevertheless, in the case of so large an area as that of the Veld, it is difficult to imagine an uplift to proceed with such perfect equability as not to disturb the delicate relation that must have previously existed between the well graded rivers of the peneplain and the gently sloping surface which they drained. Had there been here and there ever so gentle a warping, the rivers would have had to incise their channels beneath the plain where their slopes were increased, and would have had to aggrade the plain where their slopes were decreased, thus reestablishing the relation that warping had disturbed. Yet no distinct examples of locally incised rivers or of broad alluvial deposits were noticed during our journey of over 2,000 miles across the Veld, unless it may be that certain shallow valleys near Bulawayo are thus to be interpreted, and that the heavier local sheets of waste which we saw at a few places should be explained as the result of local down-warping, instead of being regarded as due to long-period weather variations, as has already been suggested; but these deposits are at most of small extent. As a rule, the absence of incision and of deposition would seem to disprove the occurrence of warping since peneplanation, and thus to render broad elevation also rather improbable.

It might, however, be suggested that the elevation of the region took place, with more or less warping, so long ago that later erosion has again smoothed it out to a new peneplain; but in that case one might well expect that the dissection of the peneplain as a whole with respect to present sealevel should be more advanced than it is. Indeed, it is a necessary corollary of the moderate amount of dissection that the Veld as a whole exhibits with respect to present baselevel than any elevation that it has suffered since peneplanation can not have taken place at a very remote date.

In so far as I have been able to gain information as to the dissection of the plain around its margin, it is of a kind that is equally consistent with the central up-warping of a former low lying peneplain, or with the marginal down-warping of an extensive area of arid leveling. The headwaters of various rivers that rise in the southern part of the Veld and flow southward across the Karroo and through gaps in the Cape Colony ranges to the southern coast seem to have eroded normal valleys of moderate depth beneath the highland. The retrogressive headwaters of the eastern slope have been described in previous sections as energetically occupied with the capture of quiescent headwaters from the Orange River system. But this is also just what might have been expected under the supposition of marginal down-warping after extensive arid leveling. It is, of course, possible that the fuller description of the lower course of the Orange river may give some light on this obscure point. It is known that falls occur in the lower course of the river, as already mentioned; but the relation of the falls, and of the gorges that are presumably associated with them, to the uplands and highlands is not yet made out.

There is, however, one decisive test which, when applied, would suffice to determine whether the Veld and the associated highlands—that is, the great interior mass of South Africa—has suffered a change of altitude with respect to sealevel since it was reduced to its present small relief. This test is the occurrence of indisputable marine strand lines around the continental margin. Such marks of a former seashore are reported by Schwarz as occurring along the southern coast in the neighborhood of Port Elizabeth at altitudes of from 200 to 400 feet. A sea-cut bench at that altitude is described as being "covered with undoubted marine shingle . . . sometimes associated with shell-deposits characterized by a large Petunculus" (c. 74). As to the occurrence of similar high level sea margins in Natal where they would be more directly applicable to the problem in hand, I have no information. They should be sought for, inasmuch as it is evident that they bear critically on the conditions under which the erosion of the Veld was accomplished. But it should be pointed out in this connection that the various "plateaus" or evenly eroded uplands of subaerial origin, now more or less dissected by rivers, which are reported in association with the Cape Colony ranges, are not decisive witnesses in this respect; for they may have been eroded at their present altitude with respect to a distant shoreline before the sea was brought in to its present position by down-warping or down-faulting of the lost borderland of the continent.

The possibility of arid leveling may now be considered in relation to the Veld.

THE VELD REGARDED AS A PLAIN OF ARID LEVELING

If the highland of the Veld be regarded as part of a region of arid leveling essentially at its present altitude, the whole region must surely, while the processes of leveling were going on, have had a much larger continental area than that of South Africa at present; for the theory of arid leveling at altitudes independent of the general baselevel of the ocean necessarily presupposes that the leveling processes acted over an area so large that the headward erosion of outflowing, peripheral rivers could not make itself felt. If the area concerned were small, the capture of the interior drainage systems by the peripheral rivers would permit the general degradation of the arid area with respect to normal baselevel before it could be leveled at some independent altitude, and thus only an ordinary peneplain would be produced. The highland of Tibet may be adduced in illustration of this principle. Before the mountains and basins of that lofty interior region can be worn down to a continuous rock floor of nearly level surface, the headwaters of the steep outflowing Indian rivers will have retrogressively gnawed into the plateau country and cut it to pieces, preparatory to reducing it to a normal lowland but little above sealevel, always provided that some new mountain-making disturbance does not invade the region and thus introduce a new cycle of erosion under different conditions of high and low land from those now prevailing.

It is therefore necessary, if we accept the theory of arid leveling, to regard the Veld as only a large remnant of a once much larger highland whose marginal parts have been warped or faulted down beneath sealevel. This aspect of the problem will be considered in the next section.

The large and well ordered Orange River system, already signalized as very appropriate to an uplifted peneplain, is hardly consistent with the conditions of arid leveling; for the later stages of an arid cycle are thought to be characterized by the disintegration of the larger drainage systems that might have existed during the maturity of the cycle. However, the occasional interruption of the actual drainage system by shallow depressions or "pans" favors, or at least permits, the explanation of the Veld by arid erosion, and if further study of the pans show them to be of eolian origin, it may come to be concluded that the occurrence of a large normal drainage system on the Veld today is the result of the coalescence and slight modification of many formerly independent drainage systems, in consequence of a change from a hypothetically more arid climate of former times to a presumably more humid climate of recent times.

Passarge places much emphasis on the abrupt transition between hill slope and plain surface as a feature explicable only on the supposition of erosion under an arid climate. We saw several rather striking examples of this kind in the district of the Matopos near Bulawayo and also along the eastern border of the Kalahari region, which we passed on the railway, and were disposed to regard Passarge's explanation of them as correct; but it does not follow that, because the erosion of these plains was carried on under an arid climate, they were therefore developed independent of normal baselevel. There are several arid regions in the world close to the seacoast where erosion is proceeding today with respect to the ocean as a baselevel, and it does not seem inconceivable that the erosion of the Veld, even under a more arid climate than that of today, may have been accomplished by one or more river systems which, when they had water to run, flowed to the sea, and that the present altitude of the region has been gained by later elevation.

A pertinent suggestion offered by Chamberlin is as follows: Continental quietude being assumed, it then follows that, even if the climate of South Africa had long been dry enough to permit the arid leveling of the Veld, the contemporaneous climate of the equatorial belt must have been moist enough to supply outflowing rivers; and these would have produced a low-lying peneplain by normal processes in the same period that sufficed for the production of the high-lying Veld by arid processes. The equatorial belt of Africa is, however, not a lowland but a highland, and its chief river, the Kongo, has falls near its mouth. Relatively recent uplift is thus indicated with a great degree of probability in the Kongo basin, the fundamental postulate of continental quietude is thereby contradicted, and the probability of uplift in South Africa is greatly increased. The only escape from this conclusion seems to be a change of climate sufficient to make even equatorial Africa arid; but this goes beyond the bounds of reasonable occurrence. The peneplanation of the Veld at its present altitude consequently seems improbable.

It remains, however, to consider one aspect of the matter which may eventually, when the more complete history of South Africa is worked out, come to be favorable to the supposition of arid leveling, namely, the former greater extension of the continent.

THE FORMER GREATER EXTENSION OF SOUTH AFRICA

It has been frequently suggested that South Africa once possessed a greater land extension to the east, south, and west. There appear to be many facts in favor of this view. If the continent were once larger, the area of the present highlands must then have been drier than now, and

under such conditions the peneplanation of the highlands by the processes of arid erosion might well have taken place. Since then the depression of the outer area would have brought the sea in to the present coastline and would have at the same time given both a more humid climate to the remaining highlands and an effectively lower baselevel to their rivers, and thus the dissection of the highland, now in progress, would have been initiated. The evidence of the former greater extension of South Africa now to be presented, as the first step in this series, may not be regarded as absolutely conclusive, but it is certainly highly suggestive and deserving of further study.

First, in regard to the heavy sandstones of the Cape system: The source of these sediments is not surely known, but the curious analogy already pointed out between the folded structure of the Cape Colony ranges and the folded structure of the Alleghenies in the eastern United States tempts one to think that the sediments of the Cape system may have come, in part at least, from the south or beyond the border of the present continent. In the Alleghenies, as in the ranges of southernmost Africa, a heavy series of stratified rocks has been pushed into parallel folds over part of their area, while the remaining area of the series still preserves its original horizontality with insignificant modification in an adjoining plateau, overturned folds and overthrust faults in both of the mountain belts being directed toward the plateau area. In the Alleghenies the source of the sediments was demonstrably on that side of the folded belt which lies away from the plateau area, and if this analogy has any value the source of the sediments in the South African ranges should also be on the side away from the plateau—that is, in a former land, now submerged in the ocean to the south of the present continent.

A second point to be considered concerns the geographical conditions prevailing during the deposition of the heavy series of strata of the Karroo system, certainly of great thickness in its area of greatest accumulation. The entire series is free from marine sediments; it begins with the remarkable Dwyka glacial formation, and then continues as a great series of continental deposits, containing fossils of land plants and land animals. The stratified beds of the Karroo system, like so many other continental deposits, have been explained as of lacustrine origin, but they are much more plausibly regarded as of mixed lacustrine and fluviatile origin. Their sediments imply a vast erosion from the contemporaneous higher peripheral areas and an accompanying slow depression of the central area or basin of deposition. There is little probability that highlands then existed next north of the present area of the Karroo system, for in that district the older Waterberg sandstones (presumably

equivalents of the Cape system) still lie horizontal. To the northwest and west the older rocks are disturbed and highlands may well have existed thereabout in Karroo time; but it is also probable that the Karroo basin was inclosed by higher land to the southeast, where the Indian ocean now stretches; for, as has already been pointed out, the oblique stretch of coast, trending northeast-southwest, distinctly bevels off a former greater extension of the continent in that direction. Indeed, in so far as this reconstruction of the physiography of Karroo time is valid, it warrants the comparison of the Karroo strata with the continental deposits now accumulating in the Tarim basin of eastern Turkestan or with the less distinctly inclosed deposits of western Turkestan. The change from that time to the present must therefore involve a considerable reduction of continental area. It may be briefly pointed out that the present relation of the Karroo formation in the Veld to so much of its original surroundings as are now visible is such as would obtain in a rather late stage of the development of a great continental basin, when the inclosing highlands and the accumulated basin deposits are both cut across by a nearly level plain of erosion, which passes somewhat below the uppermost of the basin strata, and hence all the more below the tops of the inclosing highlands; but so great a part of the rim of the Karroo basin is now lost that speculation about it can not lead to any definite conclusion.

Still further, the continent seems to have been larger than now when the Cape and the Karroo systems were deformed as well as when they were accumulating. The most manifest evidence of this statement is to be found along the oblique northeast-southwest stretch of the coast in eastern Cape Colony and southern Natal. Here the sea cuts off the eastern ends of several east-and-west members of the Cape Colony ranges, part of the relatively undisturbed basin sediments of the Karroo system, and the southern end of the north-and-south structures of Natal. The rest of the coast of Natal as well as the southern coast of Cape Colony present less apparent, but hardly less certain, evidence of a former extension seaward, for their structures are repeatedly truncated by the sea in such a fashion as to show a loss of land area. On the southwest the general increase in altitude of the Table Mountain sandstone, as one proceeds from the north-south Cedarbergen range toward the Atlantic, makes it very improbable that the land terminated at the present coastline when the deformations of the Cape system took place.

Thus it appears that possibly during the time of accumulation of the formations of the Cape system, probably during the time of accumulation of the formations of the Karroo system, and certainly during and

after the time of deformation of these systems, South Africa had a greater extension on the east, south, and west than it has now.

Fully as important as any of the preceding considerations are the inferences as to a former greater extension of South Africa, based on the distribution of fossil and recent plants and animals, as discussed by various geologists and biologists; but this aspect of the problem will not be further stated here.

In view of all these suggestive inferences, it is at least highly probable that the Veld was formerly bordered on the east, south, and west, as it is still on the north, by a large extent of land. Thus surrounded, the climate of the region would have been drier than it is now. It then seems possible that the combination of these two conditions, greater area and drier climate, both of which are essential to the accomplishment of arid leveling independent of normal baselevel, along with the third essential of a long undisturbed quiescence, may have sufficed to produce the highland peneplain in about its present altitude by the processes of arid erosion, and that the dissection which is now beginning may be the result, not of the elevation of the Veld itself, but of a down-warping of its borders, with the accompanying change to moister climate, whereby many formerly interior drainage systems might have been given free and steep discharge to the sea.

It next remains to be seen whether the date at which such down-warping could have taken place is consistent with the relatively moderate amount of dissection that the Veld has since then suffered.

DATE OF ORIGIN OF THE PRESENT COASTLINE

The occurrence of Cretaceous strata with marine fossils along the southern and eastern coasts shows that those parts of the continent at least lay close to or a little below sealevel in Cretaceous time. Hence, if the interior highland was eroded at its present height as a part of a larger continental area, the rest of which has been bent down so as to bring the sea closer to the area of the existing highland than it was originally, the diminution of size must have taken place at least as long ago as early Cretaceous time. As a result, the eastern border of the highland must have been exposed to active retrogressive erosion all through the Tertiary time. If, on the other hand, the highland owes its present altitude to uplift after normal peneplanation, the date of uplift may be associated with the movement by which the marine Cretaceous formations were exposed along the eastern and southern coasts; and this movement may have taken place in any part of post-Cretaceous time except the most recent. The question now to be determined is whether the more ancient

or the less ancient date for the origin of the eastern and southern coastline accords better with the amount of erosion that has since then been accomplished on the coastal slopes.

CONCLUSION AS TO THE ORIGIN OF THE VELD

The alternatives thus presented are clearly enough separated as far as their mental conception is concerned; but, in our present ignorance of the rate at which retrogressive erosion goes on, it seems hardly possible to make choice between the two possible conditions under which the planation of the Veld took place. If a comparison of the Veld with the Arizona plateaus is legitimate, the result of the comparison would be in favor of a later date than Cretaceous for the initiation of the eastern escarpment or continental slope from the Veld to the Indian ocean; for if a wide-spread erosion, reducing a great extent of country to a lowland (afterward elevated to plateau altitude), took place in Arizona in post-Eocene time, it would be expected that a great reduction of a highland would have taken place in Natal in both Cretaceous and Tertiary time. It is true that the rocks are not the same in the two regions; but, as far as the comparison enables one to judge, the erosion of the eastern escarpment of the Veld is less than might be expected for the work of much of Cretaceous and all of Tertiary and post-Tertiary time. For this reason, as well as for that based on the features of the Kongo basin, it seems improbable that the erosion of the Veld was accomplished by the processes of arid leveling at its present altitude. It is, however, still conceivable that the Veld is the product of arid erosion while the continent stood at a less altitude than that of today, and that the arid plain has been elevated and its discharging marginal rivers have been revived in the manner described for the case of a normal peneplain. No decisive choice seems possible at present among these baffling alternatives.

Continental Analogies

The preceding paragraphs suggest a brief reference to a favorite topic among geographers, namely, the greater or less resemblance between different continents, which has often been taken to reveal something of the plan of continental construction or even of terrestrial deformation. Analogies of this kind were pointed out long ago, before much was known of geological structure. They were then based chiefly on continental outline, with a brief supplement of gross continental topography. With the progress of geological study, some of these analogies have gained support, others have been shown to have little or no foundation, while some new

analogies, not previously suspected, have been brought to light. Among those which find support from the facts of geological history is the analogy between North and South America, where a significant number of symmetrically placed subcontinental areas appear to be of rather similar geological development. Indeed, it may be fairly pointed out that the chief contrasts between these two typical continents do not result so much from differences in their geological constitution as from differences in their position with respect to the climatic belts whereby the South American analogue of the frozen northern parts of North America lie within the torrid zone, and whereby the South American analogue of tropical Central America projects far into the inhospitable belt of the south temperate zone and has glaciers on its shores instead of coral reefs. Among the new analogies that geology has brought to light is that most striking one between Eurasia, taken as a whole, and North America; but here the repetition of similar features is symmetrical right and left, about an Atlantic axis. It is from this analogy that one finds the best means of determining that Europe and Asia should not be regarded as two separate continents, although they certainly should be regarded as two "grand divisions" of the lands; for on matching the corresponding parts of the questionable single or double continent of Europe and Asia with the corresponding parts of the unquestionably single continent of North America it is found that Europe matches only the eastern part of North America, and that a large part of Asia is needed in supplement before the western part of North America finds its analogue. In all such comparisons the unlikenesses are not to be overlooked. They are numerous and striking in the analogy just mentioned between North America and Eurasia; but the likenesses, not merely in outline, but in geological history and structure, are still more striking and give strong support to the possibility of their resulting from a similar series of terrestrial processes.

Among the analogies of outline which find no support in geological structure and history is the one between South America and Africa. The elements of likeness, long ago pointed out, are that both these continents become narrower toward their southern extremity, to the east of which lies a large island. The broad, blunt termination of Africa is thus likened to the tapering southern end of South America, and the large subcontinental island of Madagascar is matched with the Falkland Island group. There is nothing in South Africa to parallel the lofty and modern chain of mountains that forms the border of South America on the west, nor with the extensive plains of later geological formations that in South America slope toward the eastern coast. There is nothing in southern South America to compare to the long undisturbed highland of the Veld,

eroded on Mesozoic or older rocks; nothing to parallel the well defined east-and-west ranges of Cape Colony compressed and folded in Mesozoic time and since then little disturbed. South America has gained breadth by relatively modern growth; South Africa has lost breadth by relatively modern marginal submergence.

The result of all this is that continental homologies should no more be based merely on present outline and gross configuration than should etymological analogies be based on the present appearance of words. The establishment of a historical correspondence is necessary in both cases before any real analogue can be accepted. The assumption that South America and South Africa are analogous continents is on a par with the assumed etymological relationship between carbon and charred bone. On the other hand, the search for continental analogies based on similarity of development may bring to light close relationships that would be as little suspected from outward appearance as would be the consanguinity of such words as pecuniary and fee.

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Explanation of Plates

Plate 47.—*Gorge of Buffels River and Base of Witteberg Range*

Figure 1.—Entrance to the gorge of Buffels river, south of Laingsburg, looking south.

The Witteberg series is here bent into an unsymmetrical anticline, the axis of which crosses the river near its farthest point here shown; the strata on the farther side dip gently southward; those on the nearer side are about vertical. Greatly distorted strata were seen on the left wall of the notch, just below the entrance (see page 390).

Figure 2.—Northern base of the Witteberg range, just above the gorge of Buffels river, looking southeast.

The weaker upper members of the Witteberg series here form foothills. The Dwyka tillite forms a ridge on the left, not shown in this view (see page 391).

Plate 48.—*Deformed Witteberg Series and cobble-covered Terrace*

Figure 1.—Greatly deformed Witteberg series, on east wall of lower gorge of Buffels river, south of Laingsburg.

This view, which is looking northeast, occupies the central part of figure 5 (see page 392).

Figure 2.—Cobble-covered terrace or planation surface, southwest of Laingsburg, looking south.

This shows the Witteberg range in the background. The valleys of Buffels river and its tributaries are now from 300 to 500 feet below this terrace (see page 397).

Plate 49.—*Table Mountain Sandstone and Matopos*

Figure 1.—Table Mountain sandstone in the southern part of Cedarbergen range.

The view looks east from the upper valley of Berg river. The valley is worn down on the weak axial beds of a north-south anticline (see page 395).

Figure 2.—Group of Matopos, southwest of Bulawayo.

This is a disintegrating granite knob, surmounting a widespread plain of erosion (see page 429).

PLATE 50.—*Dwyka Tillite and Witteberg Notch*

FIGURE 1.—A weathered slope of Dwyka tillite, near Matjesfontein.
The sheet of tillite slopes to the left and weathers in spiked outcrops on a faintly developed schistosity transverse to the sheet. In the distance, the west end of a synclinal ridge of overlying Ecca sandstones (see page 403).

FIGURE 2.—One side of the poort, or notch, of Witteberg river, southwest of Laingsburg.
The notch is in a nearly vertical sheet of Dwyka tillite, looking east. The attitude of the sheet is indicated by a layer of conglomerate included in it, near the left margin of the view, as well as by the attitude of bedded shales in the adjoining valley. The transverse schistosity is here well displayed by weathering (see page 404).

PLATE 51.—*Dwyka Shales and Dwyka Tillite*

FIGURE 1.—Vertical Dwyka shales.
The shales are included between heavy sheets of tillite southwest of Laingsburg, looking eastward. The white blocks are fragments of Witteberg quartzite from the terrace or planation surface which here truncates the vertical Dwyka (see plate 48, figure 2, and page 405).

FIGURE 2.—Characteristic exposure of Dwyka tillite.
The exposure is in a ravine north of Ngotsche, Vryheit, Natal (see page 407).

PLATE 52.—*Eroded Valleys and Ridges and glaciated Boulder*

FIGURE 1.—Ridges and valleys eroded on nearly vertical sheets of Dwyka tillite and shales.
The view is southwest of Laingsburg, looking west-northwest. The valley on the left is eroded on the basal shales; the valley on the right follows a weaker belt of tillite between two harder belts. The continuity of these structural features may be inferred from the continuance into the distance of the features of relief dependent on them. The poort, or notch (shown in plate 50, figure 2) is cut through the middle ridge of this view where the road from the southern valley passes through to the northern valley (see pages 397 and 404).

FIGURE 2.—A glaciated boulder of Barberton slate.
The boulder is in a ravine north of Ngotsche, Vryheit. The hammer handle is half a meter long (see page 408).

PLATE 53.—*Dwyka Tillite and glaciated Barberton Slates*

FIGURE 1.—Contact of Dwyka tillite, left foreground, against a glaciated surface of Barberton slates.

This exposure is in a ravine north of Ngotsche, Vryheit, looking northwest. The inclination of the surface of contact is an original feature, not due to subsequent tilting. The glacial striations on the slates descend to the left; they are faintly seen because the sunshine came in the same direction. Penck is standing on the upper ledge and Molengraaff to the right below (see page 407).

FIGURE 2.—A glaciated surface of Barberton slates overlaid by Dwyka tillite.

This exposure is in a ravine north of Ngotsche, Vryheit, looking north. Penck stands on the Dwyka tillite, Molengraaff stands across the contact, and Hobson is on the Barberton slates (see page 407).

PLATE 54.—*Glaciated Diabase*

FIGURE 1.—Deeply furrowed glaciated surface of diabase.

The Dwyka tillite has recently been stripped from the diabase. The view is on the Vaal river, near Riverton, 16 miles north of Kimberley, looking east-northeast. The ice-movement was toward the foreground. Some of the tillite remains in the right-hand furrow. From a photograph by Professor R. B. Young, of Johannesburg (see page 412).

FIGURE 2.—Glaciated surface of diabase.

The picture is from the same locality as the preceding view. The ice-movement was toward the background. A patch of tillite remains on the diabase at the farther end of the ledge. From a photograph by Professor R. B. Young, of Johannesburg (see page 412).

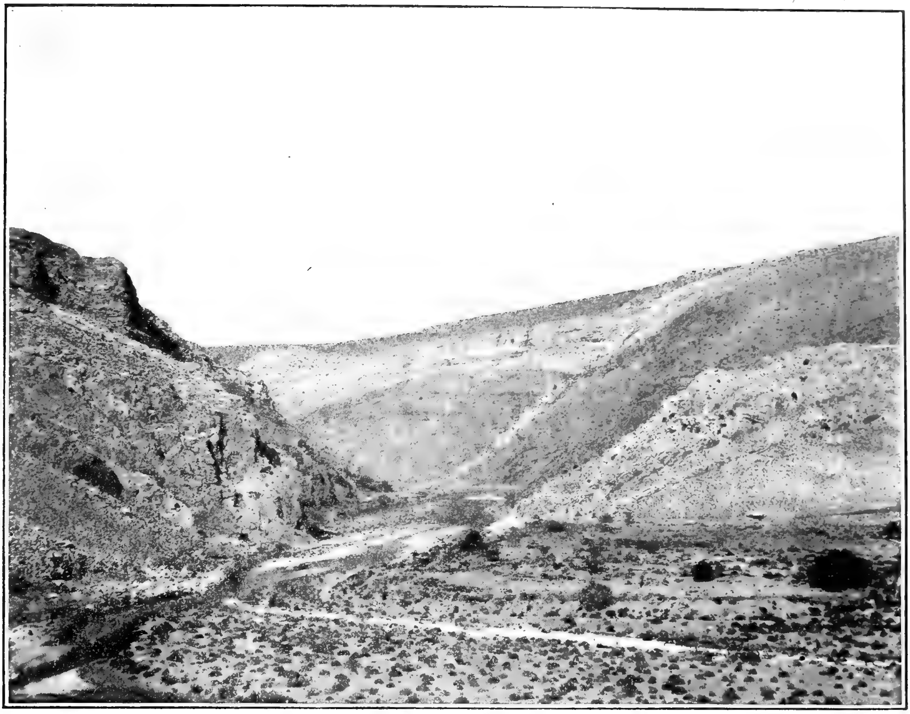

FIGURE 1.—ENTRANCE TO THE GORGE OF BUFFELS RIVER, SOUTH OF LAINGSBURG, LOOKING SOUTH

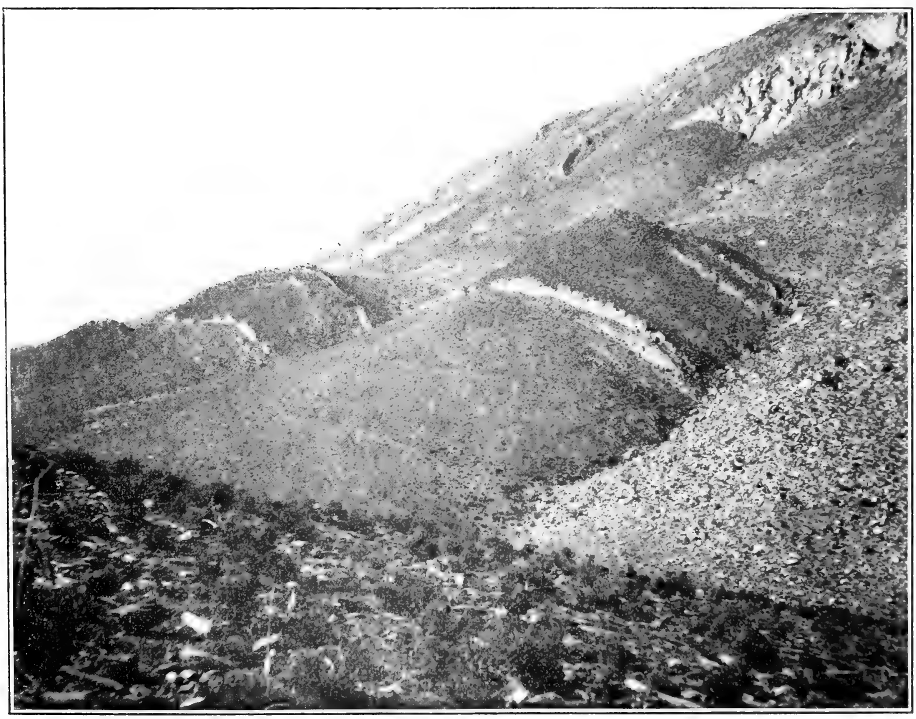

FIGURE 2.—NORTHERN BASE OF THE WITTEBERG RANGE, JUST ABOVE THE GORGE OF BUFFELS RIVER, LOOKING SOUTHEAST

GORGE OF BUFFELS RIVER AND BASE OF WITTEBERG RANGE

FIGURE 1.—GREATLY DEFORMED WITTEBERG SERIES, ON EAST WALL OF LOWER GORGE OF BUFFELS RIVER, SOUTH OF LAINGSBURG

FIGURE 2.—COBBLE-COVERED TERRACE OR PLANATION SURFACE, SOUTHWEST OF LAINGSBURG, LOOKING SOUTH

DEFORMED WITTEBERG SERIES AND COBBLE-COVERED TERRACE

FIGURE 1.—TABLE MOUNTAIN SANDSTONE IN THE SOUTHERN PART OF CEDARBERGEN RANGE

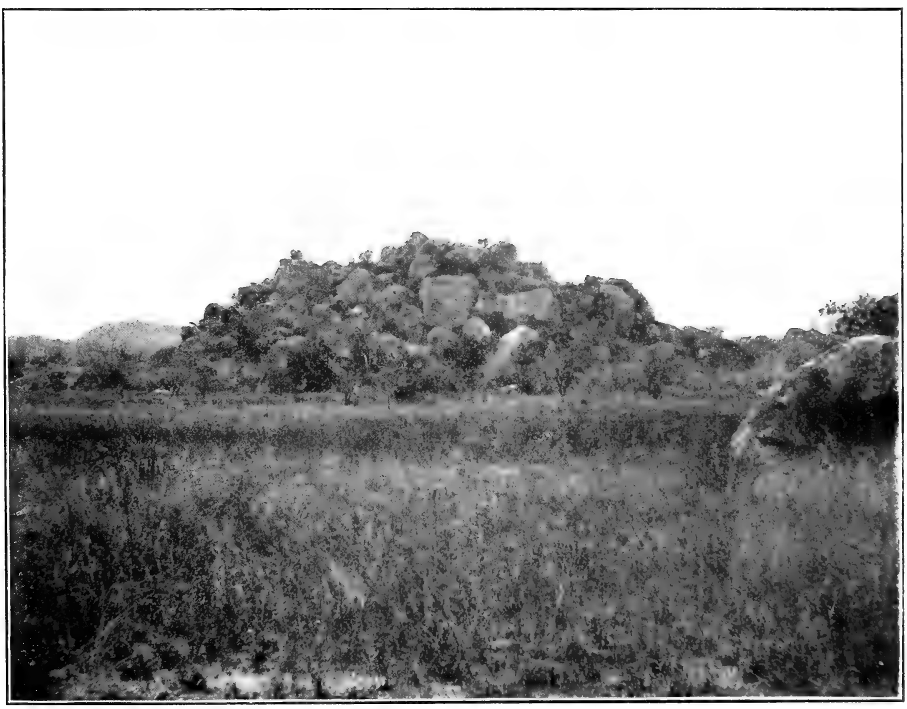

FIGURE 2.—ONE OF THE MATOPOS, SOUTHWEST OF BULAWAYO

TABLE MOUNTAIN SANDSTONE AND MATOPO

FIGURE 1.—A WEATHERED SLOPE OF DWYKA TILLITE, NEAR MATJESFONTEIN

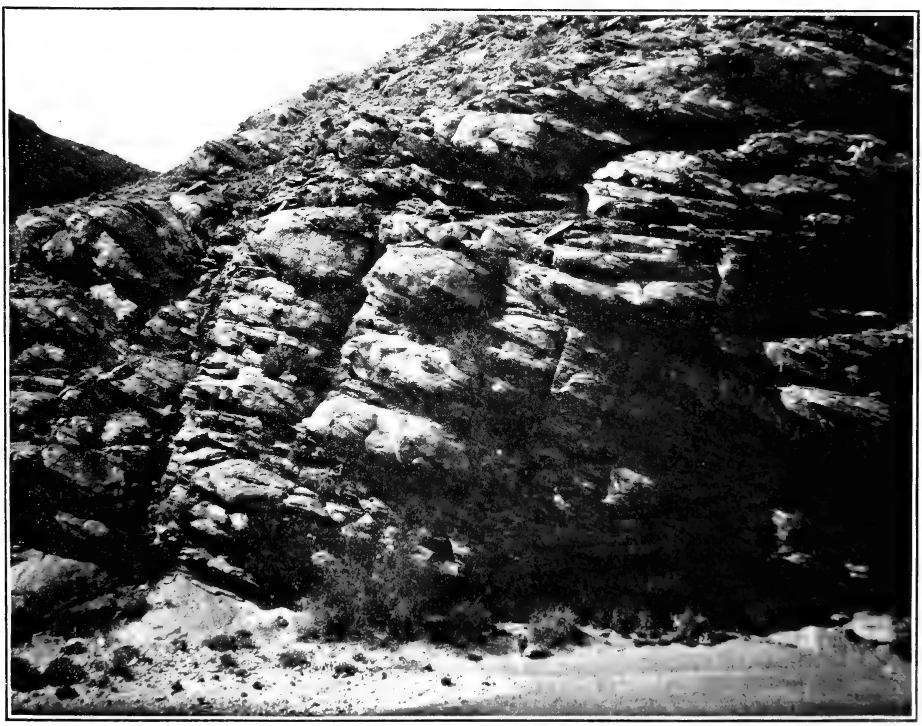

FIGURE 2.—ONE SIDE OF THE POORT, OR NOTCH, OF WITTEBERG RIVER, SOUTHWEST OF LAINGSBURG

DWYKA TILLITE AND WITTEBERG NOTCH

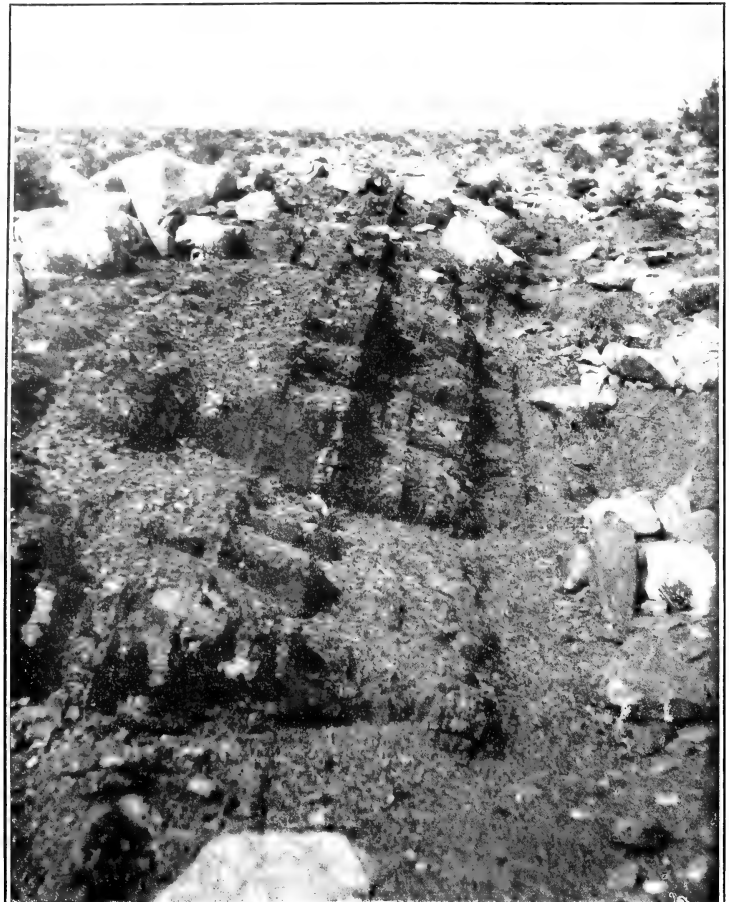

Figure 1.—Vertical Dwyka Shales

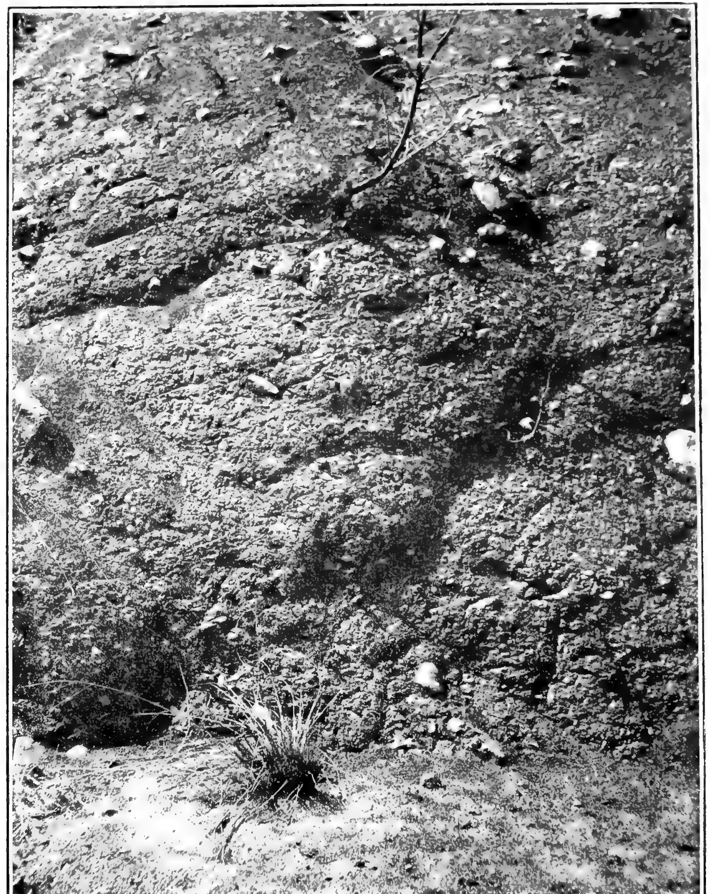

Figure 2.—Characteristic Exposure of Dwyka Tillite

DWYKA SHALES AND DWYKA TILLITE

FIGURE 1.—RIDGES AND VALLEYS ERODED ON NEARLY VERTICAL SHEETS OF DWYKA TILLITE AND SHALES

FIGURE 8.—A GLACIATED BOULDER OF BARBERTON SLATE

ERODED VALLEYS AND RIDGES AND GLACIATED BOULDER

FIGURE 1.—CONTACT OF DWYKA TILLITE, LEFT FOREGROUND, AGAINST A GLACIATED SURFACE OF BARBERTON SLATES

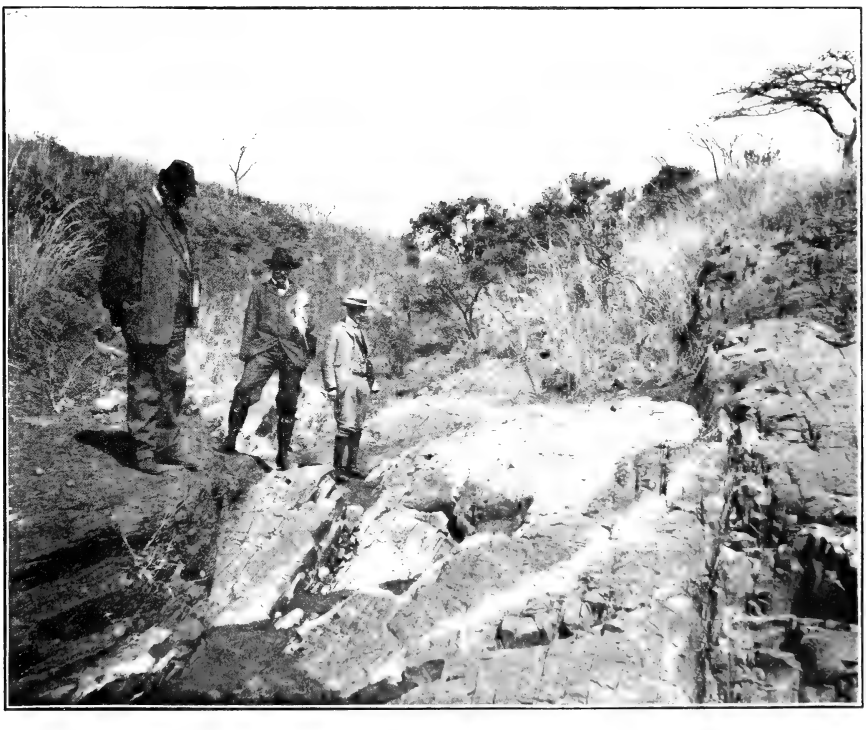

FIGURE 2.—A GLACIATED SURFACE OF BARBERTON SLATES OVERLAID BY DWYKA TILLITE

DWYKA TILLITE AND GLACIATED BARBERTON SLATES

FIGURE 1.—DEEPLY FURROWED GLACIATED SURFACE OF DIABASE

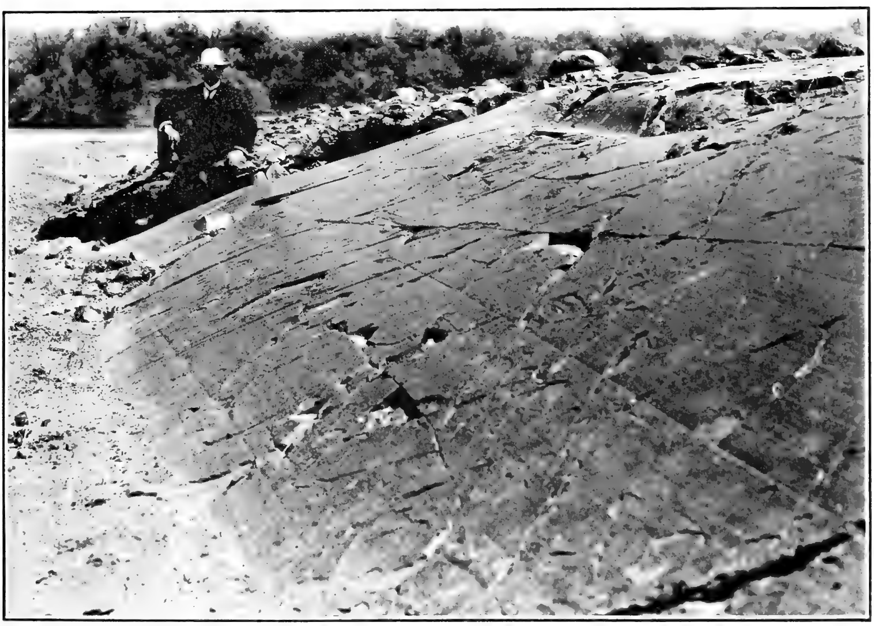

FIGURE 2.—GLACIATED SURFACE OF DIABASE

GLACIATED DIABASE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 17, PP. 451-468, PLS. 55-58 SEPTEMBER 24, 1906

GEOLOGICAL RECONNAISSANCE OF THE COAST OF THE OLYMPIC PENINSULA, WASHINGTON*

BY RALPH ARNOLD

(Read before the Cordilleran Section December 30, 1905)

CONTENTS

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Introduction

During the months of June and July, 1904, the writer, under the direction of Dr William H. Dall, made a reconnaissance of the coast of the Olympic peninsula, Washington, from Port Angeles, on the south shore of the strait of Juan de Fuca, to Grays harbor, on the Pacific. Chester W. Washburne, of Eugene, Oregon, and Russell G. Wayland, of Seattle, assisted in the work. The trip was primarily undertaken for the purpose of collecting the fossils and working out the stratigraphy of the Tertiary rocks of the region; in addition to this, however, notes were made on the other important geologic features of the country traversed. This paper embodies an outline of the results of the reconnaissance.

Mr J. S. Diller, of the U. S. Geological Survey, visited the region of Clallam bay in 1892 to investigate the coal deposits there, and Professor Henry Landes and a party consisting of Messrs Charles Landes, Charles A. Ruddy, and S. H. Richardson, made a hurried reconnaissance trip in 1902 over practically the same route as that taken by the writer, but neither Diller nor Landes published any notes on the region. It was through information furnished by Professor Landes that Doctor Dall was induced to send the writer into the country in 1904.

Previous Literature

Probably no other territory of equal extent in the United States has received as little attention from the explorer or geologist as has the Olympic peninsula, and as a result the literature directly concerned with its geology and natural aspects is confined, so far as the writer is aware, to four papers.

Mr S. C. Gilman,* a civil engineer who visited a considerable portion of the region in 1895, has given us a fairly accurate map and a good general description of the peninsula, especially the central mountainous parts.

Dodwell and Rixon,† the forestry experts who examined the Olympic forest reserve, give some notes of interest to the geologist in addition to their technical report on the forest conditions.

Some observations on the geology of the southwestern coast of the peninsula are also included by Mr H. S. Conard in an article on "The Olympic peninsula, Washington." ‡

In addition to the above, the writer has published papers on "Coal in

* S. C. Gilman: The Olympic country. National Geographic Magazine, vol. 7, 1896, pp. 133-140, pl. 16.

† Arthur Dodwell and Theodore F. Rixon: Forest conditions in the Olympic forest reserve, Washington. Professional paper, U. S. Geological Survey, no 7, 110 pages, 20 plates, 1 map, 1902.

‡ Science, N. S., vol 21, no. 532, March 10, 1905, pp. 392-393.

Clallam county, Washington,"* and "Gold placers of the northwestern coast of Washington,"† in the former of which a brief outline of the geology of the region is included. With the exception of the very brief references mentioned, nothing has been written concerning the geology or mineral resources of this extensive and interesting territory.

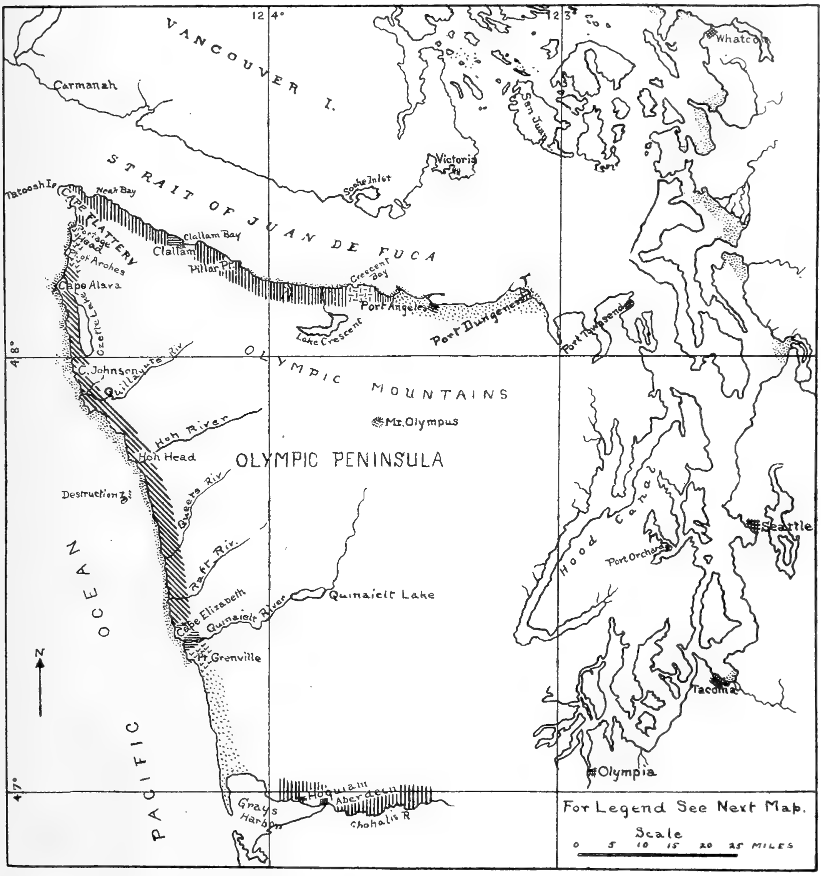


FIGURE 1.—*Sketch Map of Coast of Olympic Peninsula, Washington.*

Showing the principal geologic formations of the northern and western portions. For detail of northern coast and explanatory legend see figure 2. Topography from Coast and Geodetic Survey; Geology by Ralph Arnold, 1904.

LOCATION

The Olympic peninsula occupies an area of about 8,000 square miles, approximately 80 miles east and west by 100 miles north and south, in the

* Contributions to Economic Geology for 1904. Bulletin no. 260, U. S. Geological Survey, 1905, pp. 413-421.

† Ibid., pp. 154-157, fig. 11.

northwestern part of the state of Washington. As implied by the name "peninsula," this body of land is almost completely surrounded by water, the Pacific ocean bounding it on the west, the strait of Juan de Fuca on the north, Admiralty inlet, Hood canal, and other portions of what is popularly known as Puget sound on the east, and Grays harbor and the Chehalis river on the south. It embraces the whole of Clallam and Jefferson and portions of Chehalis and Mason counties. Cape Flattery at the northwestern corner and Port Townsend at the northeastern are its most commonly heard place names.

Topography and physical Features

THE OLYMPIC MOUNTAINS

The natural and commercial development of the peninsula is dominated by the Olympic mountains—a rugged group, occupying with their foothills the greater part of its territory. The higher mountains* are Alpine, with sharp spires and serrate ridges from 6,000 to 8,000 feet high, culminating in mount Olympus, with an altitude of 8,200 feet. They form a circular area 40 miles in diameter in the east central part of the peninsula and are characterized by glacial sculpture, precipitous slopes, and abundance of high barren and prairie land.

West of the region of high mountains the ridges rise to approximately a plane surface that slopes gently seaward from an elevation of about 4,500 or 5,000 feet. This surface truncates the deformed strata of the Solduck region and probably represents a peneplain.

The following paragraph, descriptive of the Olympic mountains, is an abstract of an article by Chester W. Washburne, now in course of preparation, which will appear in a more extended report on the geology of western Washington.

The drainage of the region is radial, the radial pattern being very perfect about the borders of the higher mountains, while within the mountains it is less perfect. The streams of the peninsula are arranged much like the spokes of a wheel, of which the region of high mountains is the hub. This pattern could have one of three possible origins: First, the drainage was initiated on a volcanic accumulation about a center; second, the drainage was initiated on the domed surface of Tertiary strata, which has since been removed by erosion; third, the drainage was initiated on the domed surface of a peneplain. By all of these hypotheses the streams are consequent to some imaginary surface of double curvature. The first

* See topographic map accompanying Professional paper, U. S. Geologic Survey, no. 7, "Forest conditions in the Olympic reserve, Washington," by A. Dodwell and T. F. Rixon.

FIGURE 1.—VIEW LOOKING EAST ALONG STRAIT OF JUAN DE FUCA JUST EAST OF GETTYSBURG

Showing the general shore conditions where no bluffs skirt the coast. Photograph by Chester W. Washburne, 1904

FIGURE 2.—CHARACTERISTIC MOSS-COVERED EXPOSURE OF SOFT OLIGOCENE-MIOCENE SHALE

Locality is between Crescent bay and Gettysburg; Pillar point to the west in the distance. Photograph by Chester W. Washburne, 1904

is disproved by the absence of extensive volcanic material. Choice between the second and third hypotheses is not wise at this time, but there are fewest difficulties in the acceptance of the third hypothesis, that the drainage results from the doming of a peneplain.

THE COASTAL REGION

The coastal region of the peninsula consists essentially of an elevated terrace. Into this the encroaching waters of the ocean and strait have eaten their way, forming precipitous cliffs along the shore. With the exception of low stretches between Tree bluff and Pillar point and in the immediate vicinity of Clallam and Neah bays, the platform varies in elevation from about 50 to 250 or 300 feet. The Terrace is by no means level, being cut by numerous streams and only in a general way conforming to a plane surface. Prominent ridges rise above the general level of the terrace, notable examples being that between Freshwater and Crescent bays and that between the mouths of the Pysht and Clallam rivers. The western border of the peninsula is also a terrace which, in some places, is over 200 feet in altitude. In occasional regions along the ocean, however, lowlands skirt the shore, as, for instance, at the mouth of Queets river. From Point Greenville to Grays harbor the border land is all low.

Figure 1 of plate 55 illustrates the usual conditions where no bluffs skirt the shore. Timber comes down to high-tide level and the beaches are strewn with huge logs which have been undermined and finally washed loose where the sea has cut into the timbered terrace region.

The coast traversed presents an unusual number of interesting physiographic features, mostly those resultant from an encroaching sea. A wave-cut platform skirts nearly the whole shoreline from the vicinity of Freshwater bay to cape Flattery and thence down the coast to point Greenville. Its surface is approximately horizontal and is usually largely exposed at low tide, in some places extending out over half a mile from the shore (see plate 55, figure 2, and plate 58, figure 1).

In certain localities along the strait of Fuca where the terrace truncates, soft shale interbedded by occasional hard thin layers of sandstone, the latter, in fragments varying from cobbles to blocks of considerable size, forms a most effective protecting cover of shingle over large areas of the platform. Even where the rocks of the coast form extremely resistant cliffs, the waves have made their impression, the result often being a narrow terrace with a cave or niche cut into the base of the cliff. An excellent illustration of this latter phenomenon is exhibited at the mouth of the Pysht river and is shown in plate 56, figure 1. At the base of the island in figure 2, plate 56, is another example of a wave-cut niche.

Along the ocean front of the peninsula from cape Flattery south to point Greenville the wave action is more intense and the resultant terrace more pronounced. The terrace is nearly 2 miles wide in the region of the Bodelteh islets, at the mouth of the Ozette river, its surface studded with small islands and sharp rocks, the latter often exposed at low tide but covered when the tide is in. It is this island and rock-studded terrace which has been responsible for so many wrecks and which inspires the navigator with such dread of the western coast of Washington. Islands of all sizes and in all stages of development, from partially isolated promontories (see plate 57, figure 1) to the typical rock-bound forms, are found here. Destruction island is the largest of the true islands along western Washington.

The shoreline conditions along the eastern end of the strait of Fuca are decidedly unlike those of the portion of the coast just described. From the vicinity of Freshwater bay eastward to Port Townsend the coast consists of steep bluffs of more or less incoherent Pleistocene deposits from which two prominent and interesting sand spits extend into the strait. Both spits are long and narrow and bowed, although extending in a general way parallel to that part of the coast on which they are developed. Both protect navigable bays on their inner sides. The spit at New Dungeness is particularly noteworthy because of its form, the main spit having a secondary one developed on its inner side (see figure 2). These spits are due to the strong tidal currents which flow through the adjoining strait, sometimes at the rate of 5 or 6 miles an hour.

Owing to the heavy precipitation on the peninsula (Neah bay, in the northwestern corner, having the maximum mean annual rainfall for the United States), many rivers rise in the central portion of the Olympics and descend through deep, precipitous canyons to the more nearly level border lands, and thence out into Puget sound, Fuca strait, or the Pacific ocean. These rivers are navigable only for canoes, and for these only in the lower channels, but they offer an unlimited field for the development of cheap power.

Flowing northward to the strait are the Dungeness, Elwha, Lyre, East and West Twin, Pysht, Clallam, Hoko, and Sekiu rivers, besides numerous smaller rivers and creeks, while the western portion is drained by the Ozette and Quillayute rivers and the latter's tributaries, the Dickey, Soleduc, Bogachiel, and Calawa. Farther south, and also draining not only the western but the southern flanks of the Olympics, are the Chahlatt, Hoh, Queets, Raft, and Quinaielt rivers. Three important inland bodies of fresh water are found on the flanks of the range adjacent to the

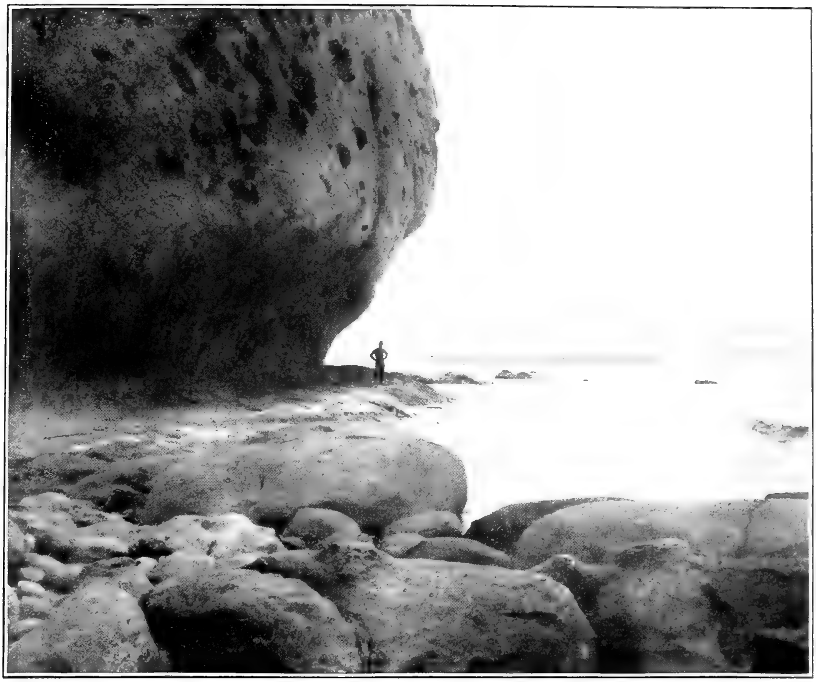


FIGURE 1.—WAVE-CUT NICHE AT BASE OF CLIFF, PILLAR POINT, LOOKING WEST

Photograph by Professor Henry Landes, 1902

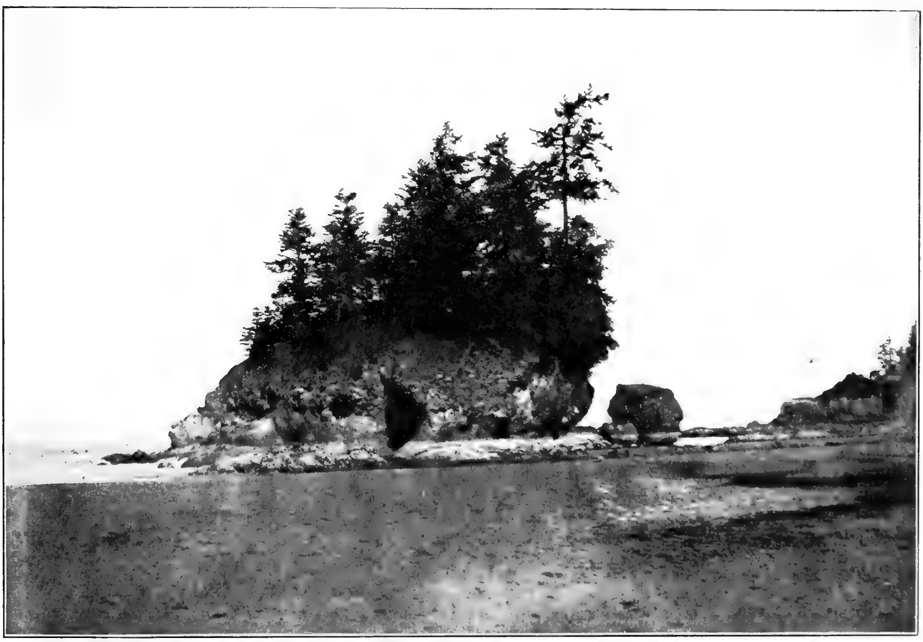


FIGURE 2.—THE BEGINNING OF AN ISLAND

Showing an isolated portion of the old terrace of basalt and basalt tuff, with wave-cut niche at base, eastern end of Crescent bay. Photograph by Professor Henry Landes, 1902

coast covered by the reconaissance. These are lake Crescent, situated at an elevation of 550 feet in the foothills 7 miles inland from Port Crescent; Ozette lake, which lies in the lowlands of the central western portion 2 miles from the coast, and Quinaielt lake, about 20 miles inland from the mouth of the Quinaielt river.

The whole country below timberline, which in this region is at an elevation of approximately 5,500 feet, is heavily timbered with hemlock, cedar, spruce, fir, etc. Between the larger trees is a dense undergrowth of devils club, sallal, brakes, ferns, and vines, which offers an almost impenetrable barrier to ordinary progress.

The country is sparsely settled, the few settlements being located in the lowlands flanking the mountains, and all, with two or three exceptions, being situated on the coast. Excluding several short logging roads, no steam transportation is carried on in the northwestern part of the peninsula, all of the freighting being done either by pack animals, wagons, or the steamers which ply between Seattle and the ports along the strait.

Geology

THE OLYMPIC MOUNTAINS

Previous knowledge of the region.—Little is known of the geology of the central portion of the Olympics because of the inaccessibility of this inner country. Mr Gilman,* in referring to the Olympic country in general, says:

> "The country rocks of the mountains are syenite, gneiss, quartzite, protogene, crystalline and chlorite schists, slate (hard black flinty to soft green talc), shale, sandstone, trap and basalt."

Dodwell and Rixon,† who examined the Olympic forest reserve, say that "no granite (except a few boulders), slate or porphyry has thus far been discovered on the reserve."

No sign of vulcanism, either in the rocks or in the pebbles of the Quinaielt or Queets rivers, was seen by Mr H. S. Conard, who visited the southwestern portion of the range in 1902.‡

Probable composition.—From evidence obtained by the writer along the western end of the peninsula and by Mr Chester W. Washburne in the Soleduc River canyon south of lake Crescent, it appears probable that at

* National Geographic Magazine, vol. 7, 1896, p. 138.
† Professional paper, U. S. Geological Survey, no 7, 1902, p. 19.
‡ Science, N. S., vol. 21, March 10, 1905, p. 392.

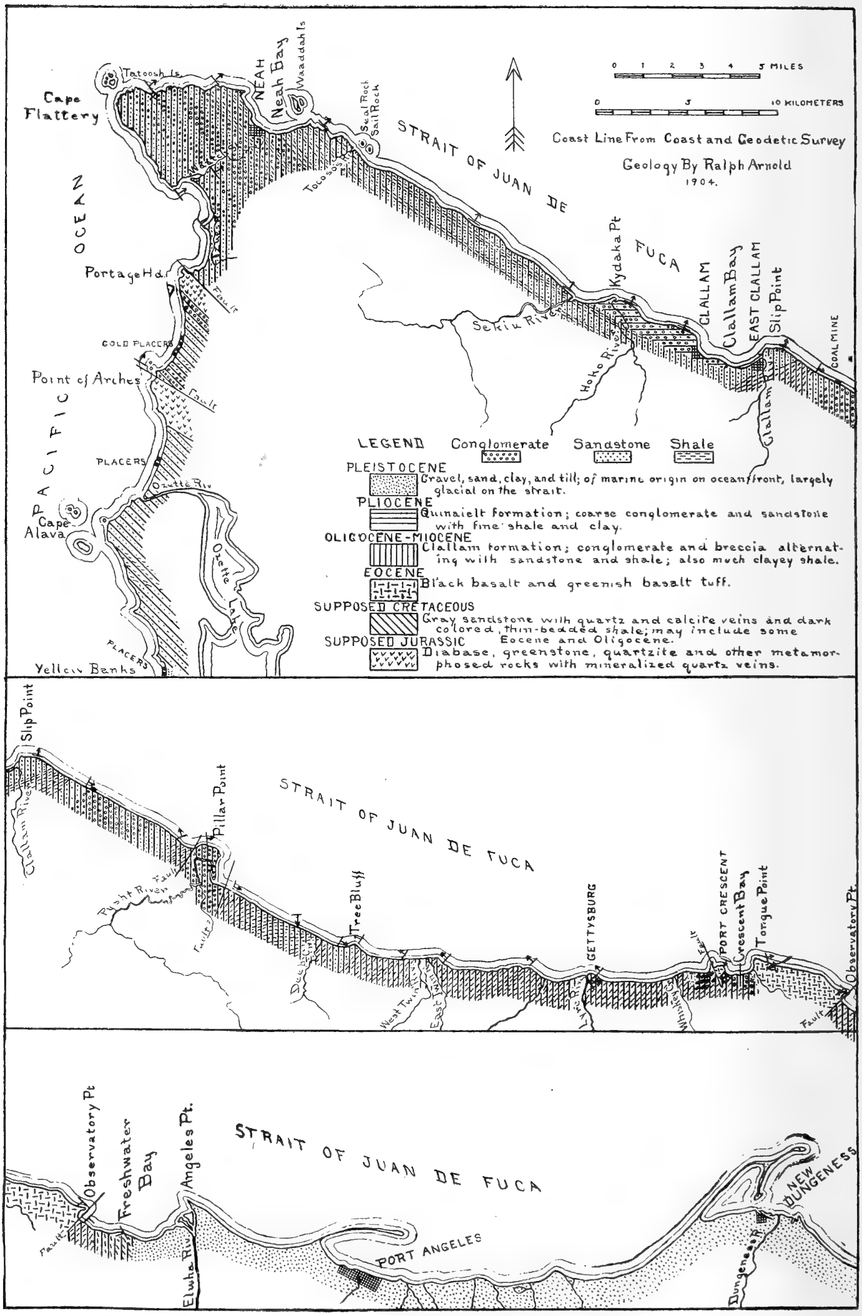


FIGURE 2.—*Detail Map of Geology of Coastline from Cape Flattery and Vicinity to New Dungeness*

least the greater part of the Olympic mountains is composed of a hard gray sandstone, certainly pre-Oligocene and probably Cretaceous in age.

THE COASTAL REGION

Geologic formations.—The formations involved in the geology of the coastal region of the Olympic peninsula include serpentine, old diabase or greenstone, metamorphosed sandstone and quartzite, probably of Jurassic age; 6,000+ feet of gray sandstone with minor quantities of carbonaceous shales, supposed to represent the lower part of the *Puget group* and of Cretaceous age; 1,200+ feet of basalt and basalt tuffs of Eocene age; 15,000 feet of Oligocene-Miocene conglomerate, sandstone, and shale; 2,260 feet of Pliocene conglomerate, sandstone, and shale, and at least 300 feet of Pleistocene till, clay, and gravel. In addition to this, the Oligocene-Miocene breccia contains large quantities of angular fragments of hard black slate, indicating a probable widespread formation of this type of rock somewhere in the general region. Nothing is known of the age of the slate except that it is pre-Oligocene.

Supposed pre-Cretaceous.—The supposed pre-Cretaceous rocks of the territory examined were confined entirely to the coast south of cape Flattery, the most important areas occurring at Portage head, 8 miles south of the cape, Point of the Arches, 3½ miles still farther south, and in the region from Point Greenville south to within a few miles of Grays harbor. The types of rock composing this old series embrace old diabase or greenstone, serpentine, quartzite, conglomerate, etcetera. These are much fractured and faulted and are occasionally cut by quartz veins, some of which, in the Point of the Arches complex, are said to carry small amounts of gold and silver. An interesting fact in relation to the conglomerate and serpentine in this same locality is the occurrence in them of a high grade petroleum. Where freshly exposed, both the conglomerate and serpentine give off a most nauseating odor, like that of benzine or some other allied product. The occurrence of the oil is made the more interesting when it is known that no shales or other possible oil-producing rocks outcrop in the immediate vicinity, although shales of probably Oligocene or Miocene age are found something over a mile south of the serpentine.

Supposed Cretaceous.—The rocks supposed to be Cretaceous in age, the correlation being based on their stratigraphic position and lithologic character, are also confined to the western coast of the peninsula. They extend over most of the territory from 1½ miles south of Point of the Arches to 1 mile north of cape Elizabeth, and consist almost entirely of a

coarse gray sandstone, with occasional zones of black shale and rarely a little conglomerate. The thickness of the formation is probably over 5,000 feet, although, owing to its complex structure, this is only a very rough approximation. The series is characterized by calcite veins, which are abundant in nearly all of the exposures. The shales carry some lignite at two or three places, at one locality in particular the coal being used locally for domestic purposes. Indications of oil are also very noticeable in a soft gray sandstone, which may belong to this series, outcropping in a canyon about a mile north of Point of the Arches. This oil has a similar odor to that found in the serpentine and conglomerate a mile or so to the north and may be derived from the shales associated with the sandstone. Indications of oil are also said to have been discovered in the

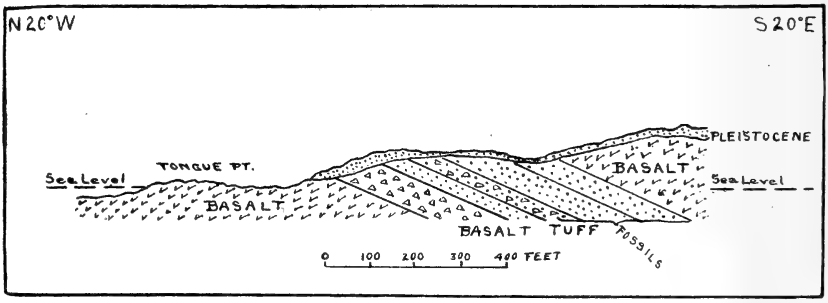


FIGURE 3.—*Section along eastern End of Crescent Bay.*

Showing the relations of the Eocene basalt, fossiliferous Eocene basalt tuff, and the fossiliferous marine Pleistocene.

sandstones and shales south of the mouth of the Quillayute river and at one or two other localities between the Quillayute and cape Elizabeth.

Eocene: Crescent formation.—The oldest formation of definitely known age on the Olympic peninsula is a 1,200-foot series of black basalt and greenish basalt tuffs and tuffaceous sands found in the vicinity of Port Crescent and here designated the Crescent formation. It comprises the region immediately west of Crescent bay and a prominent ridge extending eastward from the latter to Freshwater bay. *Venericardia planicosta* Lamarck, *Turritella uvasana* Conrad, and other characteristic fossils found in the tuff indicate the Eocene age of the series and its general contemporaneity with the Tejon of California.

The basalt occurs in two thick sheets, an upper and a lower, each of which may represent several surface flows. Between the two basalt sheets and intimately associated with the top of the lower is a series of roughly bedded fossiliferous tuffs. Figure 3 illustrates the relations of the differ-

ent beds as they occur at the eastern end of Crescent bay, while figure 2, plate 56, shows a characteristic exposure of the formation at tide level in the same region. In the region of Crescent bay the lower basalt has an exposed thickness of 200 feet, while the tuffs and upper basalt sheet each show approximately the same. The Freshwater Bay section gives basalt and coarse massive basalt tuff 600 feet, thin bedded green tuff 375 feet, and black vesicular basalt 200 feet. The base of the Crescent formation is not exposed, so that the subjacent rocks are unknown. The overlying sediments consist of coarse conglomerates separated from the basalt by an erosion interval. Faults define the contact between the Crescent formation and the Clallam formation (Oligocene-Miocene) adjacent.

These basalts and tuffs are the only rocks of igneous origin found along the whole length of the northern shore of the peninsula. Taking into consideration the volcanic activity which prevailed during the Eocene in the Cascade range, only a comparatively short distance away, this single and rather limited occurrence of eruptives seems rather remarkable. The paucity of igneous rocks, however, may possibly be accounted for, at least along the northern coastal border of the Olympics, by the fact that formations younger than the basalt are the only ones exposed, and it is possible that some of these newer rocks are underlain by the Eocene basalt series.

Oligocene-Miocene: Clallam formation.—Resting unconformably upon the Eocene and older rock of the Olympic peninsula is a series of conglomerates, sandstones, and shales rich in fossils and extensive in occurrence. The formation is well exposed in the region between Clallam bay and Pillar point, to the east, and for that reason is here named the Clallam formation. According to Doctor Dall, the fossils of the formation indicate that the basal portion of the series is Oligocene in age, while the upper part is certainly Miocene. Since the separation of the two members will necessarily have to be made on paleontologic grounds and will require a more detailed study of the material in hand than time has yet permitted, the term "Oligocene-Miocene series" will be used temporarily to designate the age of the beds. A portion of the formation is unquestionably the equivalent of the Astoria sandstones and shales occurring at the mouth of the Columbia river, 130 miles farther south.

All of the pre-Pleistocene deposits along Fuca strait from Freshwater bay to cape Flattery, with the exception of the Eocene basalts and tuffs of Crescent bay and the Pliocene conglomerate and sandstone of the Clallam Bay-Hoko River region, belong to the Oligocene-Miocene series, and at least the greater part and possibly the whole of the thick series of

conglomerates, sandstones, and shales exposed in the Cape Flattery promontory, and also the sandstones and shales exposed in the hills south of the Bogochiel river, come under the same head. The thickness of this series as exposed in sections along the strait, which, by the way, virtually parallels the strike of the beds for most of the distance from Freshwater bay to Neah bay, is about 3,650 feet. The Waatch-Neah Bay section, which cuts directly across the strike of the great Cape Flattery monocline, exposes approximately 15,000 feet of conformable strata, most and possibly all of which may be Oligocene-Miocene.

The conglomerates of the series are usually quite coarse and hard and consist of pebbles and cobbles of quartzite, jasper, black slate, and occasional granitics. They are found mostly at the base and near the top of the series along the straits and in the middle of the series on the Cape Flattery promontory. The zone of conglomerate in the middle of the Cape Flattery section may be the equivalent of the basal conglomerates of the series as developed unconformably above the Eocene around Crescent bay. If so, the sandstones at the base of the Cape Flattery section are older than any of the Oligocene-Miocene beds exposed on the strait. The base of the Cape Flattery section is unknown, as the lowest beds exposed in the section are separated from the subjacent rocks by a fault.

The sandstones of the Clallam formation are for the most part thin bedded, hard and resistant to erosion, and are extremely fossiliferous in certain localities, notably east of Clallam bay. They are found at the base and near the top of the Cape Flattery section and below the upper conglomerates east of Clallam bay.

The shale of the Oligocene-Miocene occurs principally in the middle of the formation along the strait. The lower part of the shale is thinly and plainly laminated, but higher up becomes almost massive clay. Figure 2, plate 57, shows a characteristic exposure of the laminated shale. The overthrusting of the beds exhibited at this particular locality is very unusual, as the strata along this portion of the coast ordinarily lie in low simple folds. The shale is gray in fresh exposures, but becomes more or less oxidized upon exposure. Sandstone dikes, probably derived from interbedded sandstones, cut the shales in the region east of the mouth of the Pysht river, and near Gettysburg hydrogen sulphide gas was noticed escaping from cracks in the shale along the beach. Figure 1, plate 58, illustrates the ramification of one of the dikes, while figure 2, plate 55, shows a characteristic beach formed by the truncated beds of the soft clay-shale. Fossils are abundant and beautifully preserved throughout

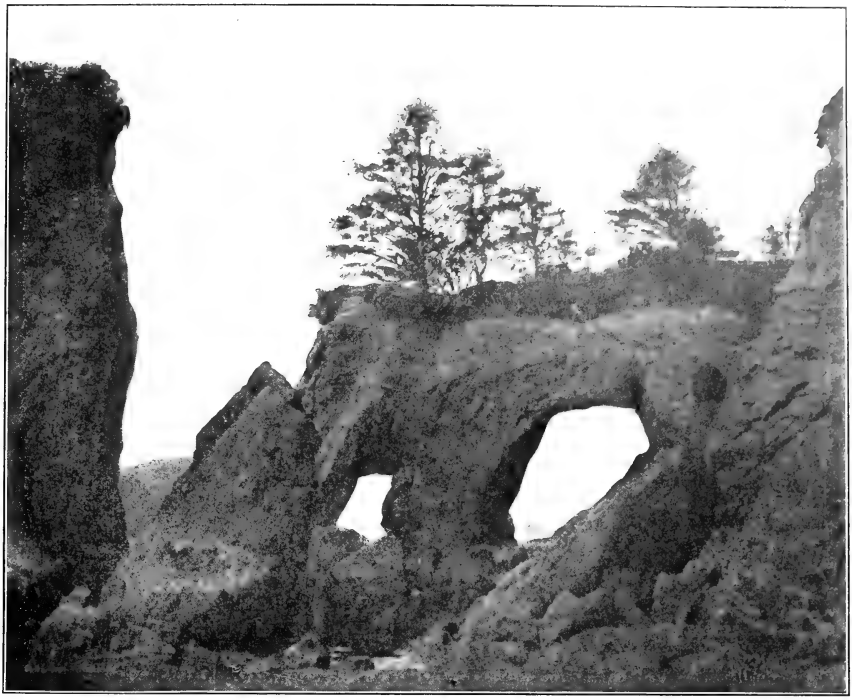


FIGURE 1.—NATURAL ARCHES IN SANDSTONE

At this locality the sea is rapidly encroaching on the cliffs south of the mouth of the Quillayute river. Photograph by Professor Henry Landes, 1902

FIGURE 2.—OVERTHRUST IN OLIGOCENE-MIOCENE SHALE, ¾ MILE WEST OF GETTYSBURG

A characteristic exposure of the shales. Photograph by Chester W. Washburne, 1904

GEOLOGIC FEATURES OF COAST OF OLYMPIC PENINSULA, WASHINGTON

the finer sediments of the series, at least two distinct horizons being recognized.

At least five recognizable faunas have so far been found in the Clallam formation. The oldest comes from the lowest clay-shales of the series and is characterized by such species as the following:

Fossils from the Clallam formation

List of fossils from the lower clay-shale (Oligocene)

Leda sp.
Pecten clallamensis Arnold.
Pecten waylandi Arnold.
Phacoides acutilineatus Conrad.
Nucula sp.
Solemya rubroradiata Conrad.
Tellina sp.
Dentalium substriatum Conrad.
Fusus sp.
Marginella or *Erato* sp.
Natica sp.
Perissolax sp.
Aturia cf. *ziczac* Sowerby.

List of fossils from the second horizon or massive sandstone

Above the clay-shale horizon is a series of medium bedded to fine massive sandstones in which are found fauna apparently transitional from the clay-shales to the coarse sandstones. This sandstone horizon has yielded the following fauna:

Cytherea cf. *vespertina* Conrad.
Leda sp.
Nucula sp.
Phacoides acutilineatus Conrad.
Solemya rubroradiata Conrad.
Tellina (*Angulus*) sp.
Thracia cf. *trapezoides* Conrad.
Cylichna petrosa Conrad.
Dolium petrosum Conrad.
Fusus sp.
Natica sp.
Perissolax (?) sp.
Pleurotoma sp.
Scala sp.

List of fossils from the third horizon or Miocene sandstone

Still a third fauna, later than the last, is represented by the following species found immediately east of Clallam bay:

Arca sp.
Chione (aff.) *temblorensis* Anderson.
Cytherea cf. *vespertina* Conrad.
Pecten fucanus Dall.
Pecten propatulus Conrad.
Tellina arctata Conrad.
Fusus oregonensis Conrad.
Natica sp.
Sigaretus scopulosus Conrad.

List of fossils from near the top of the Clallam formation

The fourth fauna is that found in sandstone layers interbedded with conglomerates in the upper part of the formation, and is:

Chione aff. *temblorensis* Anderson.
Mactra sp.
Mytilus aff. *mathewsonii* Gabb.
Panopea generosa Gould.
Pecten fucanus Dall.
Phacoides acutilineatus Conrad.
Tellina sp.
Crepidula præerupta Conrad.
Dentalium substriatum Conrad.
Fusus sp.
Scala (*Opalia*) sp.

List of fossils from the equivalents of the upper beds of the Cape Flattery section

The fifth fauna of the Oligocene-Miocene is that found at the mouth of the Sekiu river in beds the equivalent of the uppermost strata of the Cape Flattery section. The relation of this fauna to those just given is somewhat problematical, although it appears quite likely that the former is younger than most of the latter.

Cardium aff. *quadrigenarium* Conrad.
Leda sp.
Mactra sp.
Nucula sp.
Tellina aff. *bodegensis* Hinds.
Yoldia sp.
Cancellaria sp.
Cylichna sp.
Dentalium sp.
Fusus sp.
Natica sp.

Correlations.—Correlations between the different fossiliferous localities of the Oligocene-Miocene series over the whole of the Peninsula and Puget Sound region are comparatively easy, as are also correlations with certain of the Oregonian faunas such as those of the Astoria shales and sandstones, but when it comes to making direct correlations with the Californian or Alaskan faunas much difficulty is encountered. One of the greatest surprises the writer had in all of his work along the straits was his inability to find the characteristic upper Miocene fauna of the Sooke beds which are so well developed only 15 miles to the northward on Vancouver island. With an almost unbroken series of Miocene faunas one would certainly expect to find the Sooke species somewhere among the lot, but such was not the case and no plausible explanation of their absence has so far presented itself.

Coal in the Clallam formation.*—Coal occurs in the sandstones east of Callam bay in the upper part of the Oligocene-Miocene series and in the base of the same series in the vicinity of Freshwater bay. Three well

* Bulletin no. 260, U. S. Geological Survey, 1905, pp. 413-421.

defined layers, 12, 22, and 36 inches in thickness, are exposed in the first locality, while in the second 28-inch and 56-inch beds are said to occur. The coal is a hard, glossy black lignite and is, according to Mr Campbell, well adapted for gas-producer engines.

Pliocene—Quinaielt formation.—The Pliocene has a very limited development on the Olympic peninsula, only two areas of importance occurring on its coasts. The more important of these is a great syncline between capes Elizabeth and Greenville through the trough of which the Quinaielt river empties into the sea. The formation in which this syncline is developed is therefore named the Quinaielt. The Quinaielt consists of over 2,200 feet of conglomerates and shales, with minor quantities of sandstone. The conglomerates are developed north of the river, while the shale, with some underlying sandstone, occurs south of it. Owing to the fact that faults limit the syncline on both sides, it was impossible to determine positively which facies of the formation, the conglomerate or the shale, was the older. However, it appears most likely that the latter represents the basal portion of the formation. The beds contain well preserved marine fossils and the conglomerates in particular considerable quantities of almost unaltered wood and bark of trees, often in large fragments.

Fossils from the Quinaielt formation.—The following fossils, which locate the formation in the lower Pliocene and indicate its contemporaneity with the Purisima formation of central California, were obtained at the mouth of Quinaielt river, at various horizons throughout the series.

Terebratalia cf. *occidentalis* Dall.
Leda sp. (short and smooth).
Lima cf. *hamlini* Dall.
Macoma sp.
Mactra sp.
Pecten hastatus var. *hericius* Gould.
Solen sicarius Gould.
Tapes cf. *staleyi* Gabb.
Thracia trapezoides Conrad.
Yoldia cf. *cooperi* Gabb.
Anachis sp.
Chrysodomus aff. *tabulatus* Baird.
Cylichna sp.
Margarita sp.
Natica clausa Broderip and Sowerby.
Opalia cf. *borealis* Gould.
Pleorotoma perversa Gabb.
Priene aff. *oregonensis* Redfield.
Purpura canaliculata Duclos.
Purpura crispata Chemnitz.
Purpura saxicola Valenciennes.
Solariella peramabilis Carpenter.

Beds of concretionary sandstone and gray shale, the equivalent of a portion of the Quinaielt, outcrop to the northward at the mouth of the Raft river. Another area of Pliocene also occupies the territory from Clallam bay westward to the Hoko river. The Pliocene here rests unconformably upon the upturned and eroded Clallam formation (see figure 4) and consists largely of conglomerate. In the cobbles and boulders of the con-

glomerate are numerous well preserved Miocene fossils, similar to those found at the mouth of the Sekiu river (see list). The maximum section exposed in the Clallam Bay-Hoko River Pliocene area is only 240 feet thick, but this probably represents only a part of the formation.

Pleistocene—General character of the deposits.—The Pleistocene deposits of the region under discussion consist of till, clay, sand, and gravel, mostly incoherent but sometimes locally firmly cemented by iron oxide (see plate 58, figure 2). They extend from Port Townsend along the strait to the region about Gettysburg and from Portage head to a short distance south of point Greenville, on the Pacific Ocean side. In the vicinity of Port Angeles and eastward to Port Townsend the Pleistocene is between 200 and 300 feet thick; its lowest member till, the rest of the

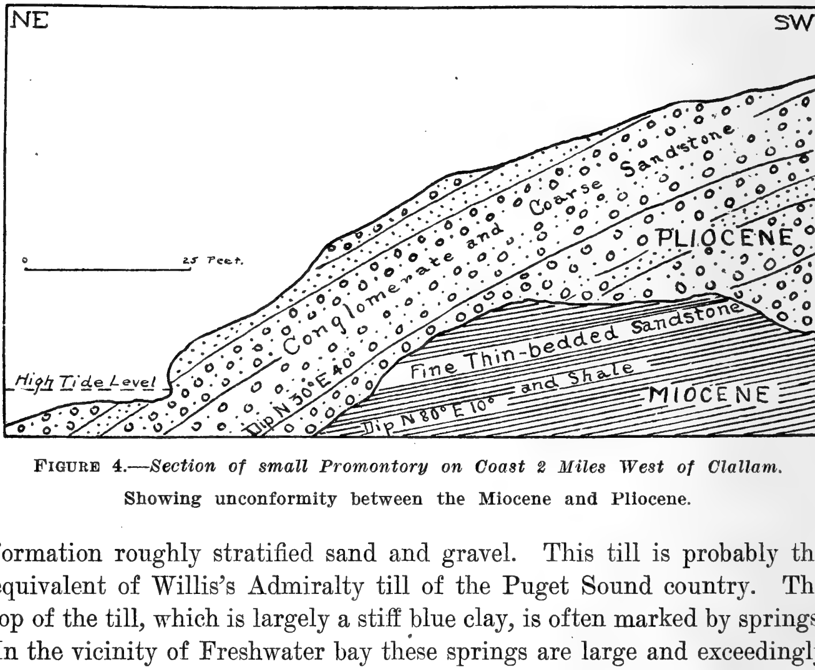


FIGURE 4.—*Section of small Promontory on Coast 2 Miles West of Clallam.* Showing unconformity between the Miocene and Pliocene.

formation roughly stratified sand and gravel. This till is probably the equivalent of Willis's Admiralty till of the Puget Sound country. The top of the till, which is largely a stiff blue clay, is often marked by springs. In the vicinity of Freshwater bay these springs are large and exceedingly numerous, and are said to have been used by the early navigators in stocking their ships with water; hence the name of the bay.

The maximum development of the Pleistocene on the western side of the peninsula is in the region about Yellow banks, 6 miles south of the mouth of the Ozette river, where the deposits of sand and gravel attain a thickness of over 125 feet. The marine origin of at least a part of the Pleistocene deposits along this part of the coast is attested by marine

FIGURE 1.—SANDSTONE DIKE IN SOFT OLIGOCENE-MIOCENE SHALE
Three-fourths of a mile east of East Twin river. Photograph by C. W. Washburne, 1904

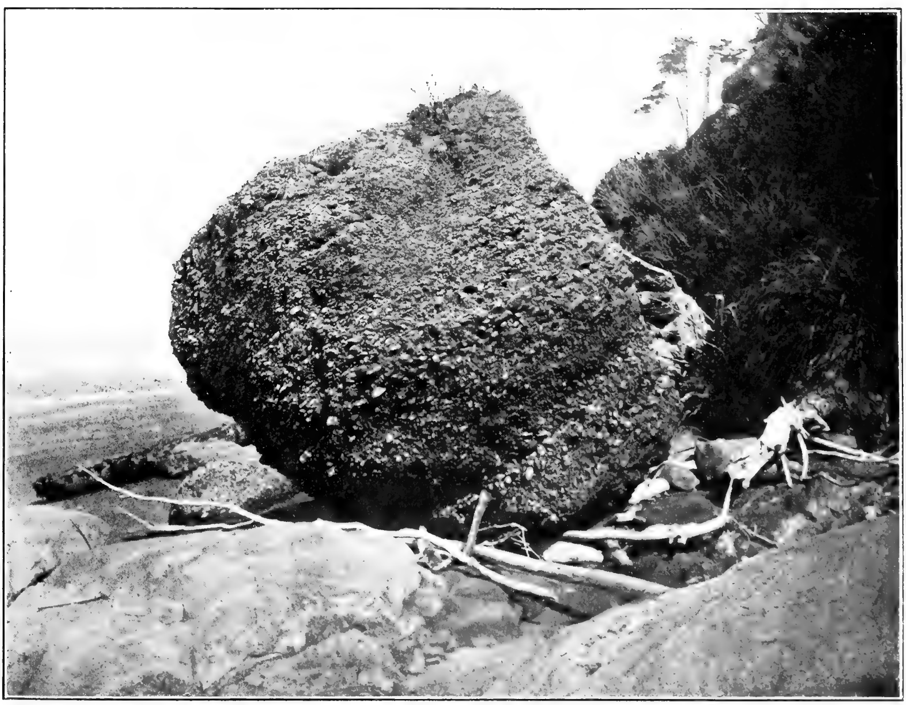


FIGURE 2.—BOULDER OF PLEISTOCENE GRAVEL ON BEACH SOUTH OF MOUTH OF QUEETS RIVER
This gravel is firmly enough cemented by iron oxide to be considered a true conglomerate. Photograph by Professor Henry Landes, 1902

fossils, which are found in fine stratified sands 35 feet above tide level near Point of the Arches.

Gold in the Pleistocene gravels.*—In certain localities the Pleistocene deposits which constitute or cap the bluffs from near Portage head south to Yellow banks carry small amounts of gold, platinum, and iridosmine. By a process of wave action these metals have been concentrated on or near the bedrock at the base of the bluffs, sometimes in quantities of economic importance. The gold and other precious metals in these beach deposits are always associated with magnetite and garnet sand, although the places richest in the "indicators" are often barren of the gold in paying quantities.

Mining has been carried on in the region since 1894, and during this period at least $15,000 has been taken from the Shishi Beach placers between Portage head and Point of the Arches alone. Besides the Shishi Beach workings, there are paying claims being worked intermittently 2 miles north of the mouth of the Ozette river, and at Yellow Banks, 6 miles south of the mouth of the same river. The mining is carried on principally by the sluice-box method, although where the water supply is limited, as at the locality 2 miles north of the Ozette, rockers are used.

GEOLOGIC STRUCTURE IN GENERAL

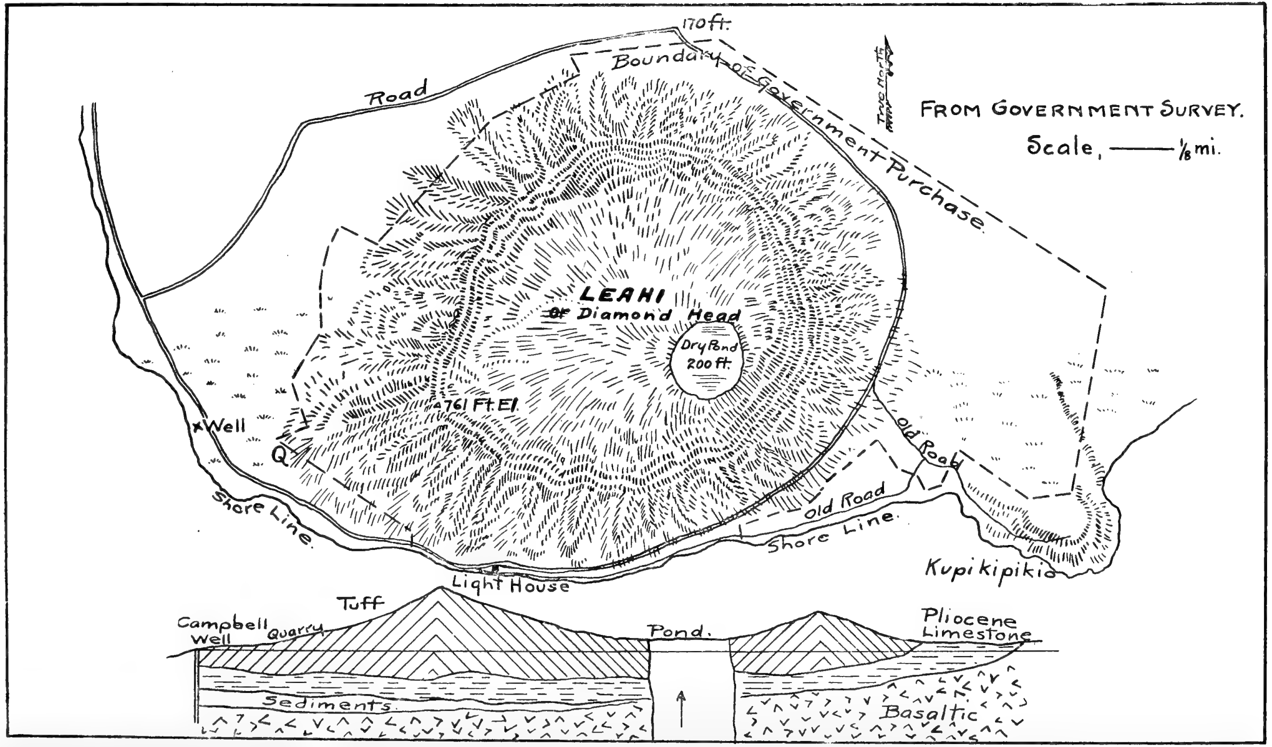
As indicated by the exposures along the coast, the structural lines in the region from Port Angeles to Gettysburg average approximately parallel to the trend of the Olympics, north 70 degrees west, south 70 degrees east; those in the Gettysburg-Clallam Bay territory almost perpendicular to this, or a little east of north, and those in the Clallam Bay-Cape Flattery stretch north 30 degrees west, south 30 degrees east, or again parallel with the ridges which extend along the coast in this region. A syncline, with its southern limb resting against the sandstones south of lake Crescent and its northern one truncated by the waters of the strait of Fuca, is the major structural feature of the Port Crescent-Gettysburg region. From Gettysburg westward to the mouth of the Pysht river the structural features are not pronounced, the rocks in general, however, having a westward dip. A rather broad syncline, with its axis extending in a northeasterly-southwesterly direction, occupies most of the territory between the Pysht river and Clallam bay. This syncline is complicated in its southeastern portion by sharp local folding and some faulting. The region between Clallam bay and cape Flattery is formed by a great northeast-

* Bulletin no. 260, U. S. Geological Survey, 1905, pp. 154-157.

dipping monocline, the beds of which appear to have a total thickness of over 15,000 feet.

South of the Clallam Bay-Cape Flattery monocline is the western extension of the axis of the Olympic mountains. The structure in the region about this line of disturbance is quite complex, but as one goes away from it toward the south the structure becomes simpler. Several determinable folds with northwest-southeast axes were noted along the coast between the Ozette and Hoh rivers, and in the vicinity of the mouth of the Quinaielt there is a very prominent syncline developed in the Pliocene, with its axis parallel to those just mentioned.

A great uplift in the Olympic Peninsula region appears to have taken place at or near the close of the Miocene epoch, and still another lesser one during the late Pliocene. That orogenic movements are still taking place, or have occurred since the deposition of the Pleistocene, is evidenced by the very gently folded and tilted clays, sands, and gravels in the vicinity of Port Angeles.



MAP AND SECTION OF DIAMOND HEAD

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GEOLOGY OF DIAMOND HEAD, OAHU

(Presented by title before the Society December 29, 1905)

BY C. H. HITCHCOCK

CONTENTS

INTRODUCTION

The title of the paper presented at Ottawa is "Hawaiian Notes." These naturally grouped themselves into three parts: First, the facts observed in Oahu, particularly about Diamond head; second, the further study of the supposed caldera at Mokohea; and, third, the latest eruption from Kilauea. For publication I have thought best to offer the two brochures relating to Diamond head and Mohokea, which supplement

papers previously published in the Bulletin. The third topic will be treated elsewhere.

Diamond Head

This is a well formed, secondary crater, adjacent to Honolulu and so conspicuously situated that it is familiar to all travelers. Since the publication of my paper on the geology of Oahu several geologists have visited it and published their observations. As these represent divergent views, I took the pains to reexamine the locality in my last visit, in 1905, and present herewith both the abstracts of the statements of others and the results of the latest investigation.

As to the cone itself, I stated that

> "The structure of the cone is typical of its class—a broad, shallow, saucer-shaped crater, with layers dipping toward the center inside, and outside outwardly in every direction at angles of 30 to 35 degrees. It would seem that the mud was forced directly upward from the center, the surplus flowing over the outside of the cone in every direction, and after the supply had ceased to come the inner portions fell back toward the vent. The fragments consist of every variety of the older basalts, with much limestone, corals, and shells that were torn off by the ascencive force of the eruption from the coral reef beneath. The tuff is a palagonite like that of Punchbowl."*

Concerning the succession the following is condensed from page 54.† The order of genesis is: 1. The deposition of the coral reef on an ancient lava. 2. The ejection of the tuff in shallow water, bringing up fragments of the older rocks. 3. The Head was covered by vegetation, much as it is now; fragments of the tuff rolled down the steep sides, became cemented by lime, whether derived from the pieces thrown up from the underlying coral reef or from the coral beach sand blown up by the wind. Land shells flourished whose remains are abundant in the talus. 4. Submergence from 40 to 200 feet. 5. Emergence to the present level.

Of the seventeen different periods recognized on the island the following relate to the Head: Number 4, coralline and shell limestones formed in later Tertiary age. These were penetrated by several basaltic eruptions. Numbers 5 to 9 and number 10, tuff craters like Diamond head were ejected through the calcareous beds. Number 11, decay of the tuff, producing soil. Numbers 12 and 14, basaltic ejections. Number 15, the accumulation of the calcareous talus-breccia, containing the remains of land shells. Numbers 16 and 17, depression and reelevation.

* Bull. Geol. Soc. Am., vol. 11, 1900, p. 44.
†Bull. Geol. Soc. Am., vol. 11, 1900.

In presenting the views of others it will be proper to commence with the publications of Professor Dana.

Views of J. D. Dana

The lava and tuff cones of Oahu were first described in the Report on the geology of the regions examined by the United States exploring expedition. The observations were made in 1840 and the volume was published in 1849. The same description reappeared in "Characteristics of volcanoes,"* with additions.

Accurate drawings of the craters, Mauumae, Kaimuki, Diamond head, Punchbowl, and the two Koko heads, with descriptions, are presented. Mauumae is said to be a lava flow; Kaimuki is not defined, but all the others, including the three salt lake craters, are spoken of as "tufa cones." Diamond head is said to be a "fine example of the typical tufa cone in its broad and shallow saucer-shaped crater, with the stratification parallel to the bottom of the saucer and to the original outer slope" (page 293). Punchbowl is said to be composed of "a yellow to brown, in part resin-lustered, palagonite-like rock bearing evidence in its constitution and in the dip of the beds that mud-making, warm waters were concerned in the disposition; and the brown, in place of red, color is probable evidence that the temperature of the water was below 200° Fahrenheit" (page 292). He remarks that "Diamond head may have been thrown up in a single year or less" (page 295), and refers to some notable recent eruptions which had likewise been formed in a very brief time. These were, first, Tarawera, New Zealand, where "the eruption was ended and the clouds of dust gone in six hours" (page 246). Secondly, in 1883 Krakatoa accomplished its work in thirty-six hours. Thirdly, Baldaisan, in Japan, sent forth steam, dust, and possibly lava, in 1888, the action being of extreme violence. "In one hour the dust shower had mainly passed, and in five hours it had wholly ceased" (page 253).

Views of W. T. Brigham

Professor Brigham describes and figures Diamond head and its surroundings.† There is a cone of tufa whose layers have dips, probably comparable with the descriptions of Dana, and the laminæ are separated by calcareous deposits. They also contain fragments of coral in considerable quantities, undecomposed and in masses of from two to twenty cubic inches. The region adjacent is an elevated coral reef. No lavas

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* Dodd and Mead, publishers, 1890.

† Memoirs Boston Soc. Nat. Hist., vol. i, 1868.

have issued from the cone, but there is a figure showing how the tufa in one locality has been altered by contact with a heated stream of basalt flowing out of it. One can recognize the actual conditions in the view taken of the cone from Koko head, there being the central cone, the surrounding limestone, and the later basaltic flow from Kupikipikio.

Views of C. E. Dutton

Captain Dutton writes as follows about Diamond head:*

"It is composed of cinders and tuff, and is in fact an immense cinder cone. Within it is a very large crater, more than a mile across. Its rim is a sharp edge which forms a complete circle, and though higher in some portions than in others, it is nowhere broken down. . . . The outer flanks of the cone are scored upon all sides with little ravines, which give it the aspect often presented by the fronts of the Bad Lands cliffs of Dakota or of the plateau country. The cone is situated close to the sea which washes the foot of its southern slope. As we pass around the flank we find a mass of strata composed of consolidated coral sand, which is strongly cross-bedded. The highest visible exposure of this 'coral rock' is about 200 feet above the sea. That it formed once a wave-washed beach just beneath the surface of the ocean is self-evident."

He then speaks of its age as very much more recent than that of the mountains of the Koolau range, and also mentions its similarity to Punchbowl and Koko head.

Notes on the Tertiary Geology of Oahu, by W. H. Dall

These notes were appended to my paper on the geology of Oahu cited above. Doctor Dall examined the lower slopes on the south and east sides of the Head, not ascending it more than 100 feet. "The conclusion to which I came," said he (page 58), "was that the whole mass of Diamond head had been slowly deposited in comparatively shallow water and gradually elevated without being subjected to notable flexure. The ejection of material at first must have been intermittent, with long quiescent periods to enable the shore to have been repopulated with mollusks and corals. The later layers may have been more frequently ejected, as indicated by the absence of perfect fossils, or of any fossils, by the thinner calcareous and the heavier tuffaceous layers."

Also on page 60:

"To sum up, it is concluded that the reef-rock of Pearl Harbor and Diamond Head limestones are of late Tertiary age, which may correspond to the Pliocene of west American shores, or even be somewhat earlier, and in the local-

* Fourth Annual Report of the U. S. Geol. Survey, 1884, pp. 217-218.

ities studied there was no evidence of any Pleistocene elevated reefs whatever. It is probable that Oahu was land, inhabited by animals, as early as the Eocene."

The determination of the geological age of Oahu was the main object of Doctor Dall's paper, and no one has since dissented from his conclusion. His judgment of the age of the fossil shells can not be called in question. Objections have been made to his view of the structure and origin of Diamond head. Should it be proved that some of the objections have been well taken, the correctness of his main contention remains unaffected.

The first reference to Doctor Dall's views came from Dr S. E. Bishop, a resident of Honolulu, a gentleman conversant with meteorological and volcanic phenomena, at one time assistant on the government trigonometrical survey of the islands. His observations on the atmospheric appearances produced by the eruption from Krakatoa in 1883 led to the accepted use of the term "Bishop's ring" (cercle de Bishop). His paper was published in the American Geologist.*

"Brevity of Tuff Cone Eruptions," by S. E. Bishop

The foregoing is the title of Doctor Bishop's paper. The main contention therein presented is that a volcanic cone like Diamond head "could have been created only by an extremely rapid projection aloft of its material, completed in a few hours at the most, and ceasing suddenly and finally."

The first proof of this proposition is the extreme regularity of the elevated circular rim of the cone. Two-thirds of the elevated perimeter represents nearly a complete circle about 5,000 feet in diameter, and most of it is about 450 feet above sealevel. The tuff has uniform quaquaversal layers dipping outwardly about 35 degrees, but less upon the inside, pointing toward the center. The southwest angle reaches the height of 762 feet, because the strong trade wind deflected the lofty jet of tuff to leeward and piled it up disproportionately.

The second evidence of the brevity of the eruption is derived from an arithmetical computation of the time required to deposit the actual mass of the cone by a fountain of adequate height to deliver its ejecta upon the existing rim of the bowl. The total mass is thirteen billion cubic feet of tuff. This could have been discharged by a fountain with 875 feet of velocity per second, raised to a height of 11,925 feet in two hours' time. This is given as an approximate estimate only, and he is disposed to in-

* Vol. xxvii, 1901, p. 1.

crease the velocity and reduce the time, with a sectional area of 5,000 feet.

These statements of the symmetry of the cone and of the time required for the deposition of the mass are thought to forbid any other conception of formation. A very good map of the Head and immediate surroundings accompanies this paper.

Writer's Statement at the Albany Meeting

At the Albany meeting of the Geological Society of America I presented briefly the antagonistic views of Doctors Dall and Bishop and requested the opinions of the fellows present as to the proper position to be taken in the controversy. No one offered any suggestion.*

Doctor Dall's reply to Doctor Bishop

Doctor Dall comments on this paper in the American Geologist for June, 1901,† practically as follows: 1. Diamond head as described by Doctor Bishop does not exist. 2. The observations previously stated are reaffirmed. 3. The inferences are submitted to the criticism of experts. 4. The tuff is underlaid by limestone carrying Chama and Ostræa, and in the middle part of the cone there are horizontal layers of compacted coral sand out of which the calcareous snowy crusts have been bleached.

Archibald Geikie's Comment

In his text book of Geology,‡ Sir Archibald Geikie refers to Doctor Bishop's paper thus: "On the transient character of the volcanic action in the case of tuff cones, see Bishop, American Geologist, vol. xxvii (1901), page 1."

He also compares the action of Diamond head to the eruption of Monte Nuovo, near Naples, in 1538, when a tuff cone was formed in twenty-four hours. I have myself ascended the sides of this cone, which has the altitude of 489 feet, and is about one and a half miles in circumference. The larger part of the famous Lucerne lake was filled with the stones, scoria, and ashes ejected in 1538. Among the fragments ejected were pieces of Roman pottery and marine shells, which happened to be situated in the path of the ascending outburst. I have been in the habit for the past forty years of using in my lectures the history of Monte

* Bull. Geol. Soc. Am., vol. 12, p. 462.
† Vol. xxvii, p. 386.
‡ Vol. 1, p. 326.

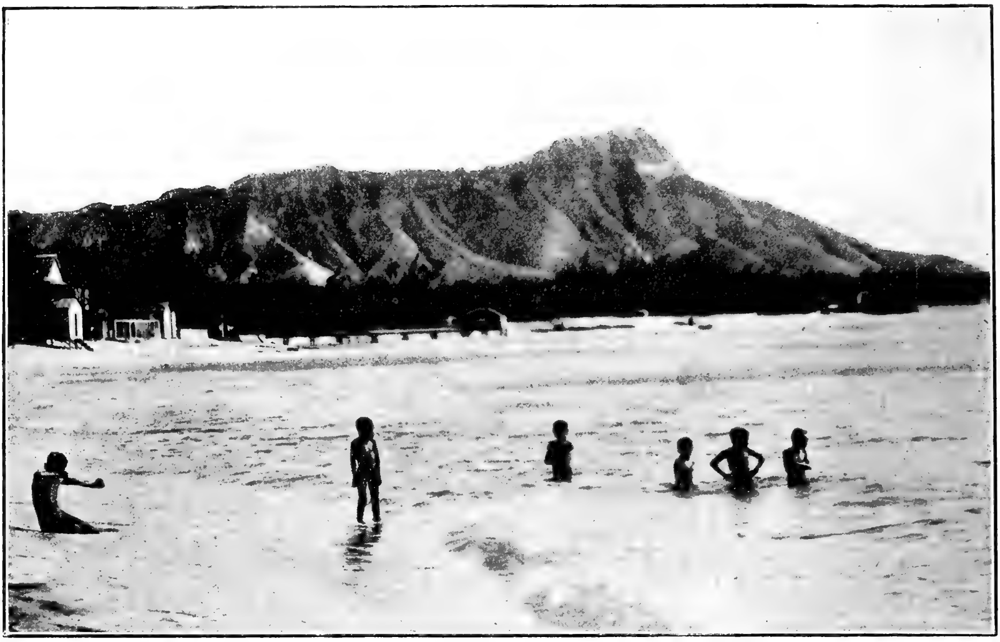


FIGURE 1.—SOUTH END OF DIAMOND HEAD FROM THE WEST

Showing layers of tuff on the crest and ravines scalloped by subaerial erosion below

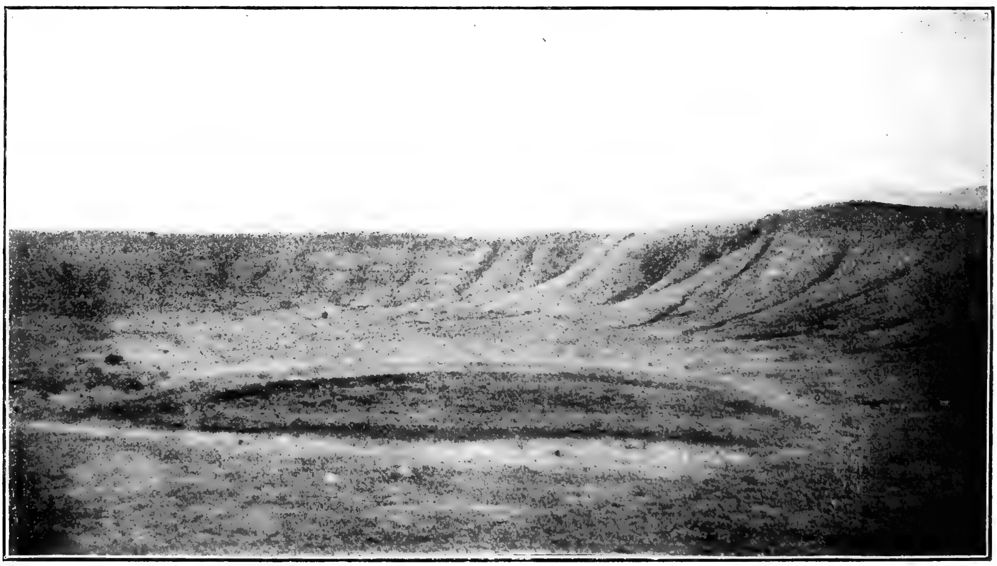


FIGURE 2.—INSIDE OF DIAMOND HEAD, LOOKING NORTH FROM THE HIGHEST POINT

VIEWS OF DIAMOND HEAD

Nuovo to illustrate the formation of tuff cones, emphasizing the brevity of the process, the stratification of the material (double quaquaversal), and the lack of any disturbances in the adjacent territory. The temple of Pluto was partly covered by the debris, but its level has not been affected, as it would have been if the cone had been formed in the manner suggested by L. von Buch and Elie de Beaumont. They believed that the conical shape proceeded from an upheaval or swelling of the ground around the vent from which the materials issued.

Dr J. C. Branner's Statement

Doctor Branner comments on the tuff and talus of Diamond head.* He finds present an extensive mass of talus overlying calcareous sand, both lying at an angle of 30 degrees; and the talus contains land shells. He thinks Doctor Dall must refer to that talus when he says the tuffs overlie the calcareous beds. He believes the tuffs were land deposits and did not come from beneath water level. Doctor Dall in his reply† calls attention to the fact that Doctor Branner did not see the region farther around the cone upon which he had based his conclusions, and that the limestones carrying the fossils (marine) could not have been a subærial formation (blown sand). Doctor Dall evidently would not disagree with the statements about the relative positions of the blown sand and the talus carrying the land shells, as both authors examined the same quarry.

Dr Whitman Cross's Statement

Doctor Cross remarks as follows:‡

> "The view of Doctor Dall that the whole mass of Diamond head had been slowly deposited in comparatively shallow water and gradually elevated without being subjected to notable flexure seems to the writer incorrect for various reasons, some of which have been pointed out by Dr J. C. Branner and Dr S. E. Bishop."

The subject was referred to incidentally in speaking of Doctor Dall's determination of the Pliocene age of the rocks in a part of Oahu.

The latest Views of Doctor Dall

Several letters have passed between Doctor Dall and myself concerning the special features of Diamond head. Explanations more explicit than those here printed have been given, and in 1905 I endeavored to visit

* Amer. Jour. Sci., vol. xvi, 1903, p. 306.
† Amer. Jour. Sci., vol. xvii, p. 177.
‡ Journal of Geology, vol. xii, p. 519.

the precise localities which he investigated and on which he based his conclusions. He was accompanied by Professor Edgar Wood, of the normal school at Honolulu, who kindly pointed out to me the route taken and the ledges examined. They did not visit Kupikipikio nor ascend the cone of Diamond head, but skirted its eastern base, from whence it was possible to see the white patches on the outer cliffs which simulated ledges of limestone. I sent an account of my explorations and conclusions to Doctor Dall, and received from him the following letter, which is published with his sanction:

"WASHINGTON, D. C., *August* 29, 1905.

"DEAR PROFESSOR: I received yours of the 22d instant this morning, and was much interested in and gratified by it, as it seems to me that it leaves hardly any unsettled points of importance in which I can not agree with your conclusions. There are one or two questions of interpretation, perhaps, to be presently referred to. You have been able, by reason of your more extended explorations of the cone at the Head, to decide several questions I had to leave open.

"Doctor Bishop's idea is, as I understand, that Diamond head was the product of a single outburst of activity, by which he may include the intermittences which usually accompany the activity of a vent forming a cone through the deposit of matter expelled at short intervals during a relatively short period of time, say within a year or two. The impression I got was that the cone was the product of small eruptions, with intervals between long enough for coral sand beaches to form or sand to be deposited by wind on the surface of ejected matter, so that there would be a certain alternation of deposits; also that this action, in part at least, took place near sealevel, with some subsequent elevation. It seemed to me that the differences between the Punchbowl (with little or no lime to be leached out) and Diamond head (so to speak, saturated with lime) was due to somewhat such a difference in method of formation. I can not otherwise account to myself for the abundant presence of lime nearly throughout the Diamond Head cone. Does it not seem, if the Bishop hypothesis be correct, as if the fragmentary lime constituents dislodged by eruption must necessarily be concentrated in the lower layers, so that, the vent once formed, there would be practically no source for fragmentary lime rock for the upper ones? If not, why do we not find fragmentary lime rock distributed through the layers of the Punchbowl and other deposits of the volcanic hills behind Honolulu? That is the way I summed it up, that in order to keep the supply of lime going there would have to be, in the case of Diamond head, quiescent periods when it could accumulate over or about the vent either from the sea or through the agency of wind. Now down by the sea I found, as I thought, some thin, continuous layers of lime rock on which were fossilized some corals, chamas, etcetera, where they grew. I recognized the exudatory character of the sheets of lime I saw on the cliffs above, but I took those near the sea to be sedimentary. If in this I was mistaken, and they were also due to exudation, it does not alter the general conditions very much. There must have been a source for the lime somewhere, and after the vent was cleared, subsequent supplies must

have come from the only possible source, direct or indirect, namely, the sea sediments and beach sand. There seemed to me to be in that cone altogether too much lime to be derived merely from the crumbling of the walls of the vent after the latter became fully established.

"I think the *marine* fossils I got around Diamond head and at Pearl harbor were indubitably Pliocene, at least they are not (so far as yet known) represented in the present fauna. Yet here we are met by the difficulty that the Hawaiian marine shells are very imperfectly known. Still, there can be no doubt that some of those I found are extinct; it is only the proportion which for the present must remain uncertain. As for the land shells in the rock at the quarry north of the road, before we turn the corner of the island. I did suggest that they *might* be Pliocene, but without dogmatism, as a decision on this point must depend on an expert and minute knowledge of the species, which I can not claim. They seemed to me wind blown, and the limestone, in which they were, to be subaerially deposited and solidified by the percolation of rainwater. This is a process which might continue indefinitely, the shells in upper layers being much younger, geologically, than those below, and much would depend on an exact stratigraphic correlation of the fossils. I found no Amastras; the others you mention are all old types which might go back to the Eocene without violating precedent. I should be much interested to see your series." . . .

Observations made in 1905

Returning now to the discussion of the observations made in 1905, it is needful to recall the general structure of Oahu. It has two ranges of basalt parallel to each other, separated by a sloping plain. The ranges are Kaala and Waianae on the southwest and Koolauloa and Koolaupoko on the northeast, the last being 37 miles long. Kaala is the oldest and is supposed to have been the only dry land for a long period. Koolau came into being later, as its discharges have covered up the eroded eastern outline of Kaala. Each basaltic mass represents an independent center of volcanic action, whether originating at the bottom of the ocean or arising from low Tertiary land. The profuse rainfall due to the impingement of the moist vapors brought by the trade winds on the highlands, has excavated numerous canyons and amphitheaters on both sides of Koolau, but with much greater erosion on the most exposed portion, looking northeasterly. For part of the way the erosion has reached the center of the range, where the sheets are disposed in an anticlinal fashion. On the opposite side the canyons, at first conspicuous, east of Honolulu are less prominent, and for a time it was believed that there was a gradual slope from the crest of the range to the valleys leading both northeast and southwest from the highest point of the plain. Now that the region has been better explored, it is found that there are deeply incised canyons along the whole southwestern slope of Koolau in the upper reaches. The

drainage is collected into Pearl river on the south, and reaches the sea at Waialua in several gulches on the north. It would seem that this intermontane plain must represent about the original surface of the lava flows, in which the gorges are few but very deep. As the surface seems to consist of soft clayey material, one would expect it to consist of sedimentary or at least ashy volcanic beds of the Tertiary. On examining the walls of the canyons the rock is made up everywhere of the spherical and elliptical nodules so characteristic of the Hawaiian basalts. They have been exposed so long to the elements that decomposition has reached the lowest depths accessible.

That part of the western slope of Koolau that is best known shows numerous secondary volcanic cones, scoriaceous, basaltic, and tuffaceous. Some are parasites on Koolau and others lie in the lowland. Scoriaceous ejections have been noted at the Pali, west of it, and near Tantalus; and perhaps the so-called ashes from Tantalus, the pond east of Kakea, and Punchbowl should be ranked in this category. Secondary basaltic ejections are recognized in Aliamanu, Aliapakai (Salt lake), near Moanalua; nephelite dikes on Punchbowl, Palolo, and Kupikipikio, the craters Mauumae and Kaimuki. For topographical reasons the interesting nepheline basalt of the Moiliili quarry seems connected with small craters lying east of Rocky hill.

All these secondary ejections named were contiguous to one another, and there is no attempt to specify the many others lying east of the region of Diamond head and west of Salt lake.

There remain the tuff cones, which mostly occupy a zone *makai* (that is, toward the sea) of the basaltic ejections. These are Makalapa, the two salt craters, Punchbowl, Diamond head, and the two Koko heads. From statements already made, these are clearly allied to the palagonite of Italy, a tuff brownish yellow in color, with a resinous luster, composed of the fragments of the earlier basalts, marine limestones, with corals and shells, hydrous and discharged at a temperature less than that of the basalts. These characteristics would seem to point to a submarine origin, while the basaltic cones, possibly coeval with them, accumulated around terrestrial vents. Diamond head is therefore a typical tuff cone, made of very hot mud, originating beneath the sealevel.

The Tertiary Limestones

All the igneous ejections, both the original Koolau basalt, the secondary scorias and basalts, and the tuff cones, have come up through a Tertiary, probably Pliocene, platform. This conclusion appeared first in

FIGURE 1.—INSIDE OF DIAMOND HEAD AND THE BLACK PROMONTORY OF KUPIKIPIKIO OUTSIDE TO THE NORTHEAST

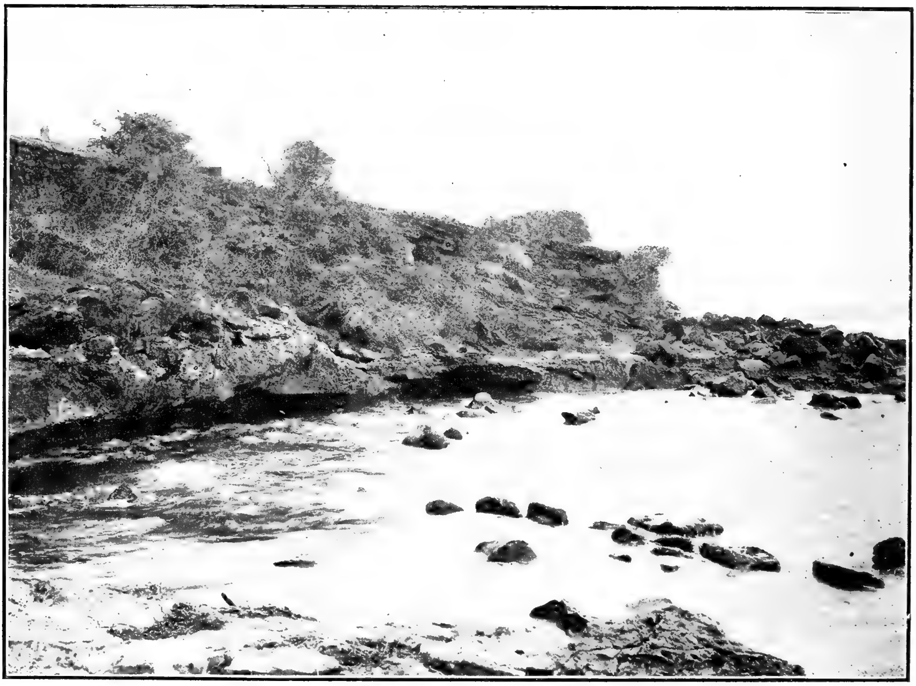


FIGURE 2.—BASALT DIKE CUTTING ACROSS LIMESTONE

ILLUSTRATIONS OF KUPIKIPIKIO

the suggestions of Dr Alexander Agassiz* as to the limestones of the Fiji islands, with the concurrent determination of age derived from a study of the mollusca of the limestones by Dr W. H. Dall, compared with the existing fauna.

It was my good fortune to be able to glance at these Fijian deposits while studying the Hawaiian phenomena, and to be satisfied of the essential unity in age of these Pacific groups of islands. Hence in my paper on the geology of Oahu† I considered the Pearl River series to be of Tertiary age, consisting of marine deposits, decayed rock, limestones, clays, pebbly layers, secondary volcanic products, ashes, and solid basalts fully 1,000 feet thick. Very fortunately Doctor Dall visited Oahu just as I was leaving and made comparisons of the shells found in the earthy deposits with those now living. Some species of Conus, Purpura, Chama, and Ostræa are apparently extinct. Hence it is as proper to call the Hawaiian beds Pliocene as those of Fiji. Doctor Dall's views on this subject are embodied in a letter published elsewhere in this communication.

The Pliocene area of Oahu coincides very nearly with the lowland tracts utilized for the cultivation of the sugar-cane and sisal, from Barbers point to Koko head. Smaller patches appear at Waianae, Waialua, at the Kahuku plantation, Laie, and other places on the northeast coast. This distribution suggests the existence of a large low island or shoal prior to the ejection of one or both of the great basalt ranges. If so, why was there not also a submarine Pliocene or older foundation for the whole archipelago? This would not render it necessary to abandon the notion, so constantly repeated, that the beginnings of land correspond to submarine volcanic eruptions.

Limestone is common over the whole plain between Ewa and Koko head, not merely at the surface, but in the artesian borings.‡ A locality of interest is just northeast of Diamond head, where Doctor Dall found fossils referable to the Pliocene. I went over the ground last summer under the guidance of Professor Edgar Wood of Honolulu, who showed me the ledges from which Doctor Dall obtained his specimens. Proceeding farther east, the promontory of Kupikipikio was found to consist of basalt, both in dikes and as a boss.

The dikes cut the limestone as illustrated in plate 61, figure 2, and plate 62, figure 1. Figure 2, plate 61, shows a black ledge of basalt next to the water, with limestone behind it higher up. The black stones to the

* Amer. Jour. Sci., IV, vol. vi, p. 165.

† Pp. 31-34.

‡ Bull. Geol. Soc. Am., vol. 11, p. 28 et seq.

right are of basalt. Above the limestone there is some ash before reaching the house. Figure 1, plate 62, shows a ledge of limestone in the midst of the ash, while beyond are the basaltic fragments detached by weathering from the boss. The locality is a field east from the house shown in figure 2, plate 61. The ash was spoken of in my Oahu paper (page 45) as being like the Diamond Head tuff. The tuff and the ash merge into each other at Kupikipikio, and the latter is also extensively spread along the road passing around the north side of Diamond head. Both probably came from the Kupikipikio ejection.

The limestone is 505 feet thick in the Campbell well on the seashore at the southwest corner of Diamond head, beneath 270 feet of the tuff.* It is thicker here than in any other of the wells of the Honolulu plain. The limestones, earths, and upper basaltic masses lie entirely to the southwest of Koolauloa. Wells sunk near the Makiki reservoir to the depth of 200 feet or more upon this basalt failed to discover any limestone, whence it is inferred that the Tertiary series, penetrated by nearly all the artesian wells in the vicinity of Honolulu, represents a later age, consisting of the coral reefs built upon the volcanics.

The black Ash

Considerable labor has been expended in determining the sources of the black ash about Honolulu, and it was concluded that it came from several craters, notably Punchbowl and Tantalus, as well as from Koko head, Diamond head, and Makalapa. A better knowledge of the conditions about Diamond head leads to the belief that the ash on its eastern side came from Kupikipikio. Since my earlier visit a good road has been constructed around the Head, and it has been possible to examine all the rocks with greater care and precision. There are beds of this ash cut by the road on the northeast and north sides of the Head, sloping toward the east. A part of the material has changed its color from black to reddish, due to weathering. It is generally much finer grained than the ash about Honolulu. It has not been observed about Diamond head elsewhere than on the Kupikipikio side, where it would have naturally fallen if ejected from the latter opening, being carried by the prevailing winds so as to fall upon the slope of the former. So also had the material come from Diamond head we should expect to find some remnants of it at least upon the leeward side. The position of Kupikipikio may be better understood by noticing the dark promontory in the distance in

* Op cit., p. 28.

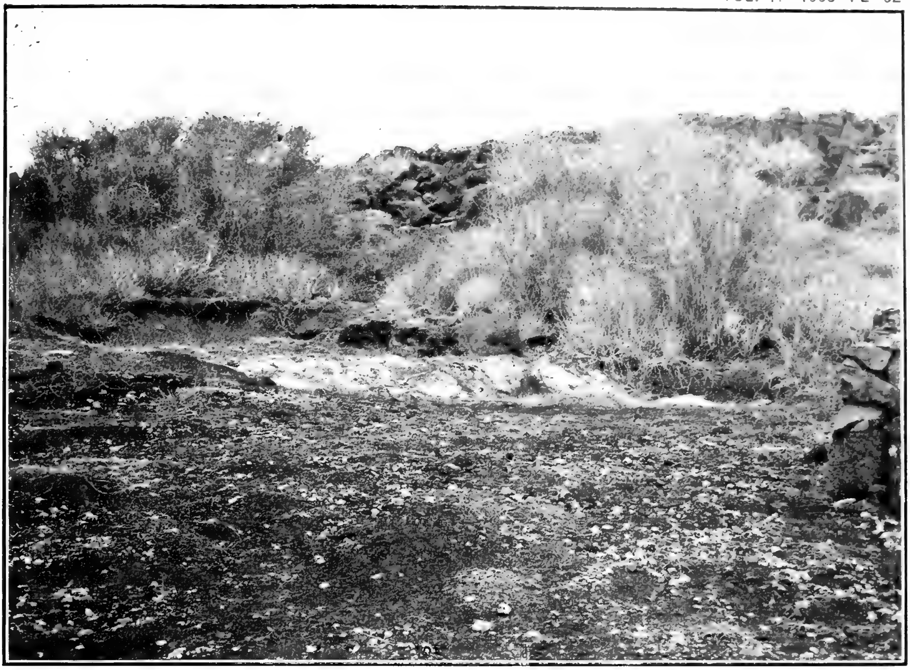


Figure 1.—Limestone protruding through Tuff and situated in Front of a Boss of Basalt, Kupikipikio

Figure 2.—Black Ash overlying weathered Tuff, Punchbowl Quarry

SECTIONS IN TUFF

the photograph (see plate 61, figure 1), taken from high up Diamond head, showing the eastern rim of the crater.

Punchbowl and Diamond Head compared

The structure of Punchbowl is like that of Diamond head. It is mostly composed of tuff, much of which on the side toward the city has its seams filled with calcite. In the quarry below the reservoir both calcite and zeolites are found, and an occasional piece of basalt. A photograph (see plate 62, figure 2) shows the relations of the tuff to the black ash. The person in the foreground stands upon the decayed upper layer of the tuff. He is looking into the excavated part of the quarry. Behind him are the thick layers of black ash. The hill in the background is Punchbowl. The phenomena prove that the black ash overlies the tuff, and that a long interval must have elapsed between the ejection of the two materials, because the inferior one has been weathered. It is probable that the first material came from beneath the sea, while the later ash, though issuing from the same vent, did not come in contact with water, and with it came another basalt, that on the summit of Punchbowl and in the dikes radiating from it. The extent of the tuff to the southwest is shown in the well boring at the Queens hospital, where 47 feet of it is reported underlying 13 feet of lime sand and 10 of black ash. The Tertiary is well shown in a cutting near by on Vineyard street, 15 feet of sand with shells being exposed beneath the black ash.

Similar relations of the tuff, soil, and ash have been observed near Moanalua, where the tuff has been covered by an ash in which may be seen upright trunks of trees.* On Fords island, in Pearl River lagoon, a thin layer of ash has been found intercalated in limestone.† Rather than assume the ashes to have been erupted simultaneously in the Honolulu district, it may be better to say that similar eolian materials have been discharged at intervals through an unknown part of Tertiary time.

Doctor Dall has noted the greater abundance of limestone in Diamond head, where the tuff is fairly saturated with it, than in Punchbowl. A walk up the southwest slope of Punchbowl will satisfy any one that the seams are as fully filled with this mineral as in the northern part of Diamond head, and in the quarry it is not wanting, accompanied with zeolites. The appearance of this calcareous incrustation is shown in the photograph (plate 63) of veins, filling seams, on the road on the east side of Diamond head. The conchoidal fracture of the larger blocks is coated with calcareous incrustations, and the vertical seams are

* Geology of Oahu, pl. 6, fig. 2.
† Op. cit., p. 52.

largely composed of the same material. It was stated above that over 500 feet of limestone underlies the south end of Diamond head, and only 30 feet in the well at the Queens hospital adjacent to Punchbowl. As the volcanic ejection brought up the underlying rock, Diamond head should show very much more of it than Punchbowl. It is also on the seashore adjacent to the reef from which come quantities of eolian calcareous sand. Punchbowl is half a mile distant from the seashore, and therefore would not be expected to be supplied so abundantly with blown sand.

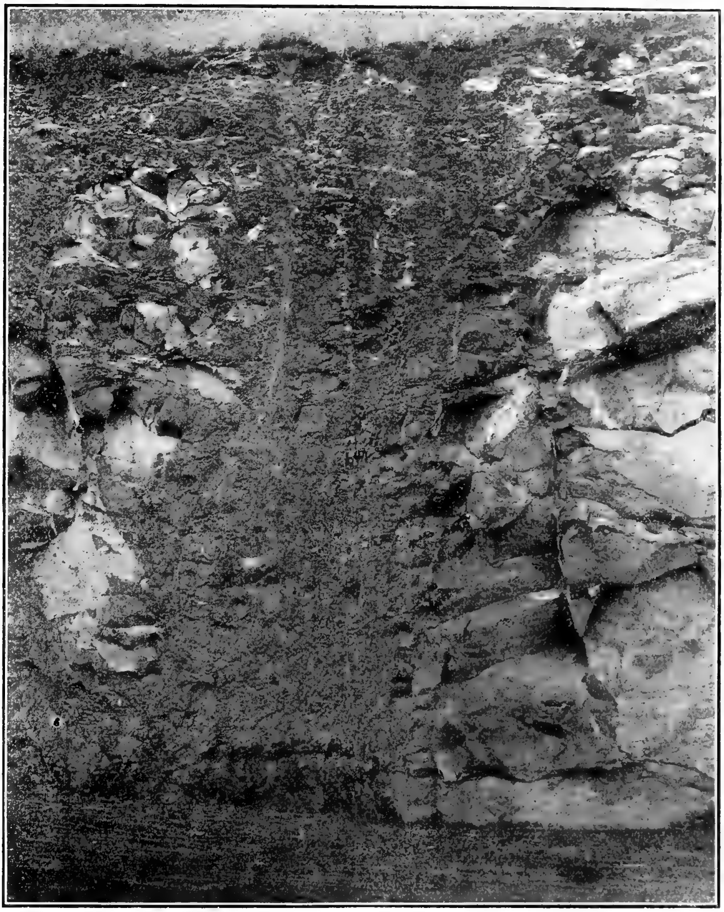
An examination on the inwardly dipping layers near the highest point of Diamond head reveals a very liberal supply of limestone. It was here that I found coral and shells in 1883. The photograph in plate 61, figure 1, shows the abundant supply in the layers of tuff in the foreground on the right-hand side. The standpoint is quite near the summit, and the view was taken to show the rim of the cone, the interior, and the black promontory of Kupikipikio in the distance.

In this connection it is proper to advert to the abundance of limestone in the inside of the crater at Salt lake. Not merely are the fragments abundant, but the original reef itself must be present.* The western Koko head is equally prolific with limestone blocks, though from a hasty examination I am not prepared to say that the original ledge can be detected. The limestone has not been seen in the lowest part of the inside of Diamond head, but there is a pond there entirely dry except after heavy rains. This is shown in plate 60, figure 2, and plate 61, figure 1, shows the character of the erosion on the west side of the Head.

The Talus-breccia Deposit with Land Shells

At the southern base of Diamond head, at a quarry not far from the terminus of the electric road (1905), is an extensive excavation in a talus-breccia of tuff with a calcareous cement. This carries shells of Lepachtinia, Helicona, Pitys, Succinea, Pupa, and *Helix lamblata*, as heretofore reported. A similar deposit may be found skirting the base of the cone, probably on every side as well as in the inside, but it is seen to the best advantage where the new road has cut into it between the quarry and the lighthouse. Near the lighthouse the specimens of shells are particularly abundant because of the greater magnitude of the excavations. To the list given above may be added Amastra and Endodonta, and Professor G. H. Perkins found in addition, lower down the cliff, the remains of crustacea. Mr C. Montague Cooke, of the Bishop Museum, has discovered additional localities of these shells upon Rocky

* Geology of Oahu, p. 38.



EXPOSURE OF TUFF, DIAMOND HEAD

Showing calcareous veins and incrustations. Exposure is on the road at the east base of Diamond Head

hill and in Manoa valley, scattered among the uncemented talus blocks of that region, and in the surface soil. The geological age of all these localities must be the same. The list of them, including a few collected by Mr Cooke and identified by him, is as follows:

Lepachtinia, five or six species; several of Amastra; Tornatella, two species; Pupa; Endodonta, two species; Helicina, one species; Succinea.

Mr Cooke speaks of them as "subfossil." It remains to be determined whether any of the species are extinct.

This talus-breccia must be newer than the date of the eruption of the tuff, because it is the same material, detached from the cliff by gravity after consolidation. The cementing substance may be either fragments of lime in the tuff or blown sand from the seashore; and there must have been quite an interval between the ejection of the tuff and the presence of the animals, because the base rock must have suffered disintegration so as to allow the growth of herbs and small trees and the migration hitherward of the Mollusca. This interval was probably the same as the one indicated at the Punchbowl and at Moanalua.

It is highly probable that these shells represent a late stage of the Pliocene, partly because they seem to be older than the existing handsome species of Achatinellidæ and partly because of the presence of a marine deposit overlying the quarry mentioned above. Two views of the origin of the Achatinella have been promulgated—the first, that of Professor Pillsbry, that it has come from a type analogous to *Limnæa,* as determined by anatomical characters; the second of a derivation from Bulimulus, because of conchological peculiarities.

The latest Submergence and Reelevation

It would seem as if there must be evidence of the submergence of Oahu after the accumulation of the talus-breccia to the depth of 250 feet. The relation of the deposit to the talus-breccia may be seen at the quarry, where at the altitude of about 40 feet there is a red earth with many marine remains directly overlying the talus-breccia. Beside the mollusca, there are corals and remains of fish. This is the only place where the relations of these shells to the talus-breccia is clear. What seems to be the same material rises to 200 feet at the north base of Diamond head and also at lower levels. I do not recognize anything like a shoreline, but the marine shells are frequent. Near Doctor Wood's summer house, near Kupikipikio, are Cypreas and Turbo, both shells and opercula. The surface is strewn with rough blocks. The shells are seen when the lava fragments are thrown to one side in a very red earth, the residuary remains of the Kaimuki lava.

A study of the fields at the Waialua plantation gives related results. The cultivated tracts seem like aqueous and residuary deposits, utilized to the height of about 300 feet. I found shells and opercula of the marine gastropods in numerous localities and Melanias up to 250 feet altitude. I had no opportunity to see these remains in any excavations; they all lie on the surface of the ground.

I think a little search will prove the existence of seacliffs toward Kaena point, to the west of Waialua. Looking from the railroad train, there seems to be three wave-cut terraces in the basalt, the highest one at about the level of the shells picked up from the sugar fields. The excavations may not be strongly marked, as it is presumed that the time of the submergence was brief; but it seems evident that there must have been a very recent depression of the island to the depth of 250 feet, very likely in the Pliocene. If so, the age of the smaller land shells in the talus-breccia will be established. As has been remarked, it would seem necessary for as long a period as that to have elapsed to account for the development of the Achatinellidæ.

Relation of the basaltic Ejections to Diamond Head

The question has arisen, What is the relation of Kaimuku to Diamond head? In my geology of Oahu (page 75) I have referred to the meeting place of the two rocks, the basalt apparently overlying the tuff. The road now passes near the line of junction of the two rocks. It looks as if the basalt had affected the tuff, the former pressing against the latter and the two interlocking.

If Kaimuki is related to the dike at Kipikipikio, it is later in origin than the tuff; or if the similar rock at Punchbowl is considered, the basalt is the newer, as it lies in the throat of the vent, adjacent to the black ash, which is confessedly the newest volcanic product. The basalts would seem to have been erupted later than the tuff, after the land had risen, because the material is neither fragmental nor hydrous. They are later than the limestones which they have cut through.

Some of the artesian wells show the presence of a thin basalt intercalated in limestone or earth, thus indicating an earlier eruption.

Conclusions

1. Diamond head is a tuff cone thrown up explosively from beneath the level of the sea, and is to be compared with the Monte Nuovo, near Naples.

2. It was ejected through fossiliferous limestones of Tertiary age, probably Pliocene.

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MOHOKEA CALDERA

BY C. H. HITCHCOCK

(Presented by title before the Society December 29, 1905)

CONTENTS

Definition and Examples

At the New York meeting* of the Society I gave some account of a singular depression on the southwest slope of Mauna Loa, calling it a caldera. My information concerning it came primarily from descriptions of the topography given by Mr J. S. Emerson, of the Hawaiian Trigonometrical Survey, which form the basis of the official map of Hawaii published in 1901. Mr Emerson had read a paper on the subject before the Social Science Association of Honolulu in October, 1895, which was published in the American Journal of Science in December, 1902, under the title of "Some characteristics of Kau." During the past summer (1905) I have visited the locality, and now proceed to describe the ascertained facts and to draw certain conclusions therefrom.

A caldera is conceived by Captain C. E. Dutton, who proposed the name, to be an immense depression "formed by the dropping of the mountain crust which once covered a reservoir of lava." The pits of

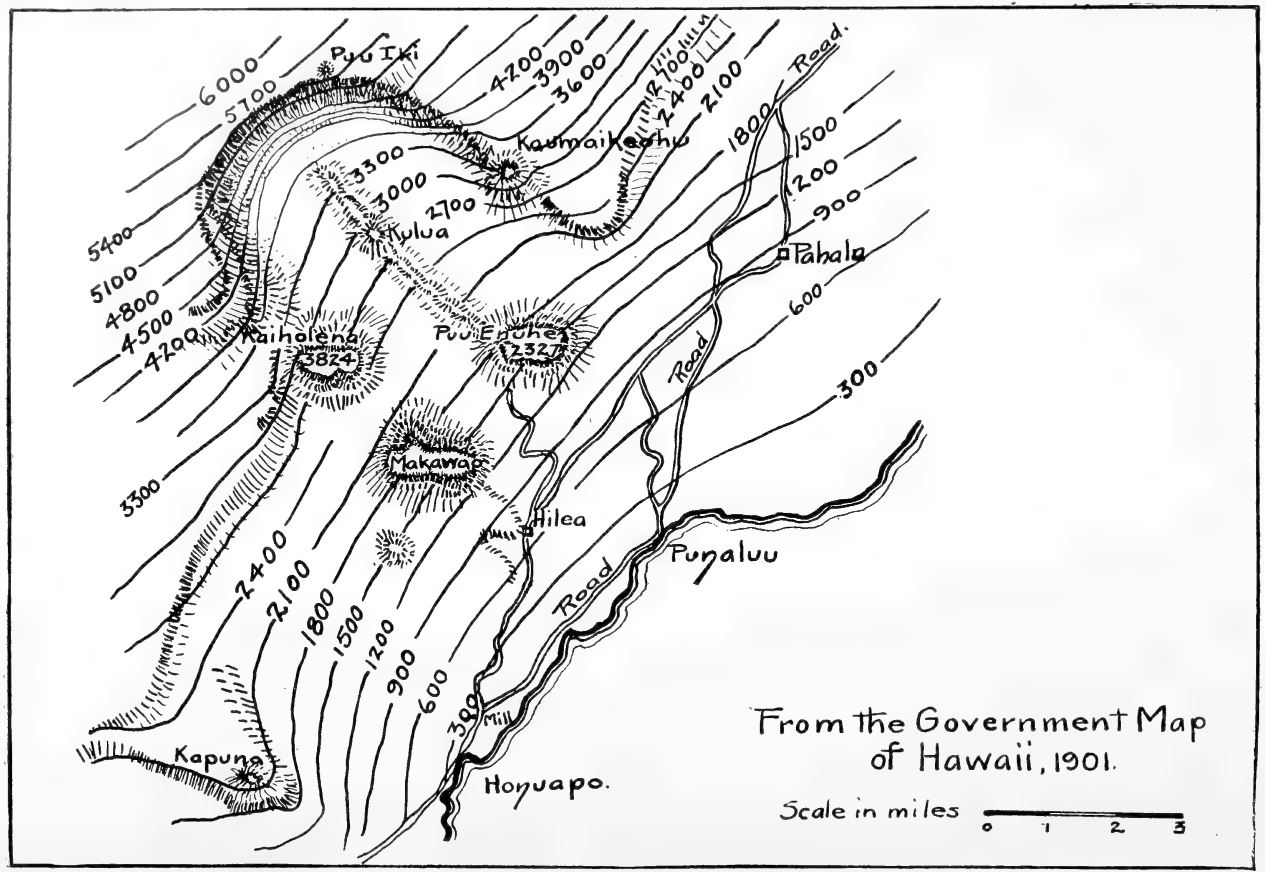
* Bull. Geol. Soc. Am., vol. 14, p. 8.

Mokuaweoweo and Kilauea on Hawaii, Haleakala on Maui, and Crater lake in Oregon are cited as examples.

Location and Peculiarities of Mohokea

The Mohokea depression is situated in Kau, in the southwestern part of the island of Hawaii, to the north of the harbor of Honuapo, which at present is the end of the sea voyage for those who skirt the leeward side of the great island on the way from Honolulu to Kilauea. There is a line of stages from Honuapo to the volcano, rising gradually for a distance of 30 miles to the altitude of 4,040 feet. Hilea, about 4 miles from the seaport, is the best point from which to traverse the depression. It is the residence of the head overseer of the sugar plantation, who very kindly accompanied me to the principal points of interest in the caldera. From the house, situated upon lava, the road ascends a steep hill covered by volcanic ashes to about 1,200 feet altitude, and thence another thousand feet to Makawao, where the soil seems to have originated from rock decomposition. This hill is on the southeast side of Kaiholena, the highest elevation in the district.

Mauna Loa is an elongated dome 13,650 feet in height, sloping gradually to the sea or to an intersection with an adjacent volcano. On the northwest side, next to Hualalei, the base is 4,500 feet; on the northeast side, next to the extinct Mauna Kea, at the sheep ranch Humuula, the col is 6,600 feet; on the southeast side, next to Kilauea, the base is about 3,800 feet. The slopes to the sea at Hilo and South cape are gradual for distances of 30 miles. The mass of Kilauea is often regarded as being on the flank of Mauna Loa, because the discharges from the latter cover up much of the former. Kilauea is as well defined a caldera, with its own periods of eruption, as Mokuaweoweo. The locations of the eruptions from Kilauea range from Nanawili, in Puna, on the east, to Punuluu on the west, which is on the seashore only 3 miles from Hilea. A very conspicuous fault extends 20 miles long from Kohaualea westerly to near the flow of 1823. The land makai (shoreward) of this fault has dropped down 1,100 feet. A somewhat similar but more irregular escarpment may be traced from near Kapapala to Waiohinu, 17 or 18 miles in length, but is on the south slope of the mass of Mauna Loa. The caldera of Mohokea has this escarpment for its southern boundary. It is an elliptical depression, 6 miles long northwest and southeast, and 5 miles wide northeast and southwest, but truncated by the escarpment named. It has been hollowed out from the basaltic sheets of Mauna Loa. The total area is about 30 square miles.



MAP OF THE MOHOKEA CALDERA

Mohokea differs from the other calderas in three respects:

1. It is not inclosed on all sides, so as to be properly a pit. It is open on the makai side.

2. There have been several flows of lava from it on the open side. (*a*) From the broadest part, between Puu Enuhe and Makawao. It is of aa, and has flowed down to the sea between Punuluu and an older similar stream toward Honuapu. It is evidently comparatively recent, though not recognizable in the legends of the oldest inhabitant. It can not have been active less than two centuries ago. (*b*) A small aa flow starts from the cliff on the west side of the gulch flanking Makawao on the west. It does not reach quite to the stage road at Hilea. It is very chrysolitic and has issued from under the later pahoehoe which overlies the yellow ash in the immediate neighborhood. (*c*) Another aa stream, still farther west, is about one mile wide where it crosses the road. It issued from the cliff on the west side of Makawao, but from between two spurs of the older pahoehoe. Following this the road traverses a mile of pahoehoe before coming to (*d*), the last aa flow, one and a half miles wide, reaching to a short distance east of the sugar mill at Honuapo. The older aa streams are covered by large kukui trees (Cordia), with their characteristic lighter yellow green color, rendering them conspicuous.

3. The greatest peculiarity in Mohokea consists in the presence of two parallel lines of faulted blocks running northwest from the southeastern edge. The one on the east is known at Puu Enuhe, rising precipitously along the edge of the cliff to the height of 2,327 feet. This is the most conspicuous of all the blocks and is the one most like the buttes of the Rocky Mountain region. The ridge behind the outer block falls away gradually for nearly 3 miles, and then rises again abruptly to Kulua, only to fall away again as at first, and reaches nearly to the innermost wall of the caldera. Viewed from a distance on either flank, the ridge resembles a huge worm with a great head and a swelling near the caudal extremity. This resemblance caught the attention of the early Hawaiians, who recite an interesting legend respecting its origin.*

To the west of Puu Enuhe lies a valley one and a half miles wide. It is inhabited by Hawaiians who exhibit characteristic features of the life of the olden time. They are highlanders as contrasted with lowlanders. On the west side the valley is flanked by stupendous blocks, of

* Very long ago there lived here a charming maiden with three brothers. Among her visitors was one possessing great attractions, who always came after dark and left before daylight. The brothers found that their sister loved this visitor, and they had suspicions that he was more than mortal. In order to satisfy themselves they seized hold of him just as he was leaving, and compelled him to remain with them. As soon as daylight came he was changed into this enormous worm. He was evidently one of those deities who could not retain the human form in the presence of mortals after daylight.

which the first is Makawao, estimated to exceed 3,500 feet in height. It is hardly separated from Pakua, which is not represented on figure , a map of this district copied from the government map of Hawaii, 1901. A broader notch separates Pakua from Kaiholena, 3,824 feet high. There are five blocks in this row, into the last of which a tunnel has been driven two hundred feet in quest of water for irrigation. The east side of this line of blocks is quite precipitous, representing the place of a fault. Both the lines of blocks have been elevated, as indicated on the map, their altitudes being greater than that of the adjacent territory. The lowland between the elevated blocks and the east side rises gradually to the steep wall behind, toward Puu iki. The land is not cultivated for most of the distance, and is covered by the original forest of tree-ferns, ohias, and other hardwood trees, similar to those seen on the volcano road in Olaa. On the west side of Pakua may be seen the bed of a mountain torrent, usually dry, but often too full of water to be safely forded. This skirts the eastern border of another lowland area like those already mentioned, save that it is cultivated and used for pasturage. It is over a mile wide and has a floor of fresh looking pahoehoe, sloping gradually to the edge of the frontal escarpment, about 1,200 feet high. Eruptions of aa have proceeded from this edge along the whole width of the caldera.

The Enuke and Kaiholena ridges are higher than the slopes of the Mauna Loa basalt opposite them, of which it is supposed they once formed a part. Hence the lowland depressions can not be regarded as the results of canyon erosion; they probably were depressed, while the blocks were elevated. Following the definition of the caldera, it may be said that portions of the mountain crust were dropped, while other sections were elevated. Its development was arrested. The making of the caldera was incomplete. Possibly the great size of Mohokea, comprising 30 square miles, while Haleakala is only 19, may have militated against the thorough fusing of the entire bulk.

Mohokea compared with Haleakala

For a further understanding of a caldera, reference should be made to Haleakala on Maui. This pit has an area of 19 square miles and the shape of an elbow. It is 4 miles across from the outer to the inner angle. The greatest length, toward (east) Kaupo, is 7.48 miles. Toward Koolau (north) the distance is 6 miles. The greatest width is 2.37 miles. The depression is 2,000 feet deep, with many small craters inside—up to 760 feet in altitude—so it is a true caldera. The north arm is called Koolau gap; the east arm is called Kaupo gap. There is a grad-

BIRD'S-EYE VIEW OF HALEAKALA ON MAUI

INSIDE OF HALEAKALA AT THE SOUTHWEST ANGLE

ual descent from the axis connecting the outer to the inner angles of the elbow in both directions. Where the outermost edges of the two arms are reached there is a more rapid descent, commencing with 6,500 feet at Koolau and 7,600 feet at the Kaupo gap.

The similarity between the Mohokea and Haleakala calderas consists in the presence of steep escarpments at the lower edges of the floor, and both are unlike the typical examples (Kilauea), in that they are open on one side, not encircled by a cliff. Haleakala could be conceived of as consisting of two smaller calderas united along the axis of the elbow; or it might be imagined as formed by the splitting of the mountain and a separation of the two parts, the space between being filled by later discharges.

The gaps are each continued in broad valleys to the sea. Koolau merges into the Keanae valley, reaching the sea at the village of that name, 9 or 10 miles long. This valley is now crossed transversely by an aqueduct fully 1,200 feet above the sea, carrying water for irrigation purposes to the sugar plantations of central Maui. The Kaupo gap extends to the sea in a similar manner, taking its name from the locality. These two streams of lava are larger than any now known elsewhere in the archipelago. If the lava should accumulate enormously in Kilauea, and one stream flow south to Punaluu and the other break through the barrier to the edge of Puna and thence to the sea, the topography of the caldera and its outflows would be very suggestive of Haleakala.

Two views of Haleakala are presented. Plate 65 is a restoration—an attempt to show the appearance of the caldera as if one were situated in a balloon a thousand feet above the highest point. It is reduced from a painting by E. Bailey, based upon W. D. Alexander's early map. Plate 66 is a photograph of the south wall of Kaupo, with views of some of the smaller craters inside the pit.

Phases in the Development of Hawaiian Calderas

It is easy to speculate on the relations of the several Hawaiian calderas.

At first there is a simple crater discharging lava from the summit of a dome.

Secondly, the lava is not produced in sufficient quantity to flow over the margin; the opening is sealed, and then the outermost crust breaks up. The crust is too vast to be absorbed; blocks of it will be elevated; other sections will be absorbed, and the outer wall on the makai side may give way. There will be discharges on the lower side. This may be the Mohokea stage.

Thirdly, all the segments of the crust fall into the reservoir beneath; vertical walls encircle a pit. This is the stage of Kilauea and Mokuaweoweo.

Fourthly, the caldera with encircling walls is formed, but the lower walls give way. Great rivers of lava flow to the sea. As the fires die down several small craters are developed on the principal floor. This is Haleakala.

Fifthly, the eruptions of the smaller craters like Halemaumau multiply and the whole pit is filled. The caldera is smothered, the smaller craters continue to be developed until the internal reservoir is exhausted. This is the Mauna Kea stage.

I could count twenty-four craters of small size visible from its summit, and the government map delineates between 75 and 80 of these cinder cones above the contour of 6,500 feet. Most of them represent the latest stages of the volcanic life of Mauna Kea and not improbably the filling of a now concealed caldera.

Volcanic Ash of Hawaii and its Source

The district of Kau between Puna and Kona is proverbially dusty. The floor is of modern lava, covered over an area of 300 square miles with a light yellowish dust. Mountain torrents have washed away some of it, revealing basalts just beginning to disintegrate; that which remains is very loose, easily moved by wind or water. In the older days the natives enjoyed jumping from a high bank into the dust, just as they might leap from a bluff into the water. Of course this material is badly cut down by teams along the roads. It is utilized for the growth of sugarcane everywhere that plantations exist on the west side of Kilauea. These soils are free from rocks and are very deep, so that a crowbar or cane may be readily thrust down its whole length, just as would be true of large piles of wood ashes in a dry country. Neither is there anything adhesive in this dust when wet. No part of it adheres to one's shoes when walking over it in time of rain.

These soils suffer badly from drought. Extensive fields will be parched and clouds of dust will be very annoying, even imparting a reddish yellow tint to the sky. When the rain comes in torrents much damage will be done to the land by the cutting of trenches and the transportation of earth. The dry and wet periods are registered in the varied and irregular length and diameter of the joints of the sugarcane stalks. In the season of drought much pains are taken to prevent the starting of fire in the grass, as it spreads long distances beneath the surface, be-

cause the spongy nature of this ash will allow the access of air to support the combustion.

It is often dangerous to traverse the forests above the plantations on horseback, because the animals unexpectedly plunge into unseen deep holes and break their legs. Surveyors find it impracticable to carry supplies to their workmen by direct routes over these soils and necessarily make wide detours.

In traveling from Kilauea southwesterly through Kau this ash first appears in small isolated areas 4 miles from the volcano, and then increases in amount and importance, and is more noticeable about the "Halfway House." Between this and Pahala certain piles of it, as at the level of 1,800 feet, resemble terraces. It is the material supporting the Pahala sugar plantations. It has been covered at various places in Kau by flows of pahoehoe. An isolated hill of this sort near the tramway a mile or more northeast from Punaluu harbor is conspicuous. As a rule, the lands near the sealevel have either lost this ash by rain erosion or it is covered by the later lava flows. Most of the peaks in the Mohokea area are capped by the ash, though it is recognized most abundantly near the southeast margin.

The promontory called Kahuku point, South Cape, and Ka Lae is likewise covered by this ash, and has attained the thickness of 10 feet, separated into two parts by a thin seam of earth. The late eruptions of 1868 and 1887 destroyed the continuity of this deposit between Kahuku and Kona.

Mr Emerson has discussed the problem of the source of the aerial eruption, and the writer has referred to the same question in a paper on the volcanic phenomena in Hawaii.*

King Umi's road is referred to as giving evidence of the presence of those ashes for three and a half centuries. He occupied a tract of land between Mauna Loa and Hualalei, where some of the edifices constructed by him were figured by Admiral Wilkes and are still to be seen. The road ran north and south, parallel to the shore of Kona, 7 or 8 miles distant, to a natural amphitheater on the southern slope of Puu o Keokeo, where immense crowds of Hawaiians gathered to witness the cock fights. The pens still stand as they were in Umi's day. The road over this ash is said to be only two or three feet wide. If a mule traversing this path deviated but a few feet on either side he would sink down to his girth and flounder helplessly. If a shower of pumice or lapilli had fallen since the days of Umi, the road and the pens would have been swept away or covered up. Hence we must regard the ash deposit as the latest formation of the neighborhood, though still several centuries old.

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* Bull. Geol. Soc. Am., vol. 12, p. 83.

Mr Emerson's final conclusion is that we must seek for the source of the ash in the district where it abounds. Considering the shape of our supposed caldera, he thinks the ashes must have proceeded from some part of it. This was the "source of the stupendous explosions or series of explosions which has rescued Kau from being a waste of unproductive rock and transformed it to so large an extent into a land of pastures and plantations."

I have already treated of this question in the paper already cited, looking to Mokuaweoweo as the probable source of this and other localities of ash on Hawaii. What is conceived to be the same duplex deposit is recognized at Puakala on the south flank of Mauna Kea, at Hilo, all through Olaa, as well as in Kau and Kona. I have the past year discovered the same deposit on the north side of Mokuaweoweo a dozen miles west of Humuula sheep station, so that now the great crater has been proved to be encircled by this light, fine grained material. The absence of it about Kilauea, Puu o Keokeo, and on the north slope of Mauna Loa is occasioned by its removal by the later historic discharges of lava. It would not be found near the central vent because the heated air would carry the particles many thousand feet in the air, whence they would descend miles away from their place of origin. The fact that the Mohokea caldera is covered by the ashes is evidence that they came from a distant vent. Had the eruption been in the midst of the depression, we should look for them in an encircling belt, if not upon the southwest side almost exclusively, where they were deflected by the trade winds.

Order of Events in the History of Mohokea

Several events can be clearly discriminated in the history of the Mohokea caldera.

1. The formation of the cone of Mauna Loa. This is really composite, but may be treated as a unity for convenience. Basalt came from below and flowed over the edge of the primeval crater till the whole dome, 75 by 53 miles in the two diameters and 13,650 feet altitude, had been formed, composed of millions of layers gradually superimposed upon one another. The altitude must have been even greater, so as to allow for the falling in of the surface to develop the caldera of Mokuaweoweo.

2. After the material ceased to flow over the surface, two styles of eruption commenced or continued to be manifested—those high up, allowing streams of molten lava to flow away quietly, and those starting from comparatively low levels, discharging with violence. The base of the cone was filled by these ruptures of the basaltic sheets and the dis-

charge of streams of melted lava. The irregularities of the southern edge of the cone from Kilauea to the South cape were produced at this time. Mohokea was the most important of these displays. The three intermontane valleys sank down in the usual style of the breaking of the superior crust from a caldera. Perhaps, because of the great size of the pit, all the fragments could not be absorbed by the inner fiery fluid; two rows of blocks were crowded up, and the work of fracture ceasing, the great masses of rock were elevated and held in position. It is to be noted that the faults are at right angles to those running seaward from the apex of Mauna Loa. This agrees with the theory of W. L. Green, that the discharges of the lava from the interior of the cone always take place at the intersection of the cross-fissures. Very much lava flowed away at this time, including the three valleys mentioned and the crust adjacent as far as to Kapuna.

3. Two great eruptions, separated by a long interval of time, threw out into the atmosphere enormous clouds of ashes. The intermediate period was long enough to allow of the invasion of plants over the sterile area of silt. Because of the occurrence of this ash entirely around the circumference of Mauna Loa, it seems most likely that the vent was at Mokuaweoweo. A gigantic cloud of steam carrying dust ascended miles into the air; the cloud rose above the trade winds and spread out on all sides, while the particles too heavy to be carried great distances fell to the ground. Three recent eruptions of a similar nature are on record—from Krakatoa in 1883, from Tarawera in 1886, and during the present year at Vesuvius. I have estimated that 2,000 square miles of the island of Hawaii were covered by these ashes. These are preserved, but they must have been strewn much beyond these limits and lost in the sea. Could any one have observed the skies at this time he would have seen repeated the sky glows, the Bishops rings, and the green sun. This must have been an explosive eruption—a style of discharge denied to Hawaiian volcanoes by the early writers.

4. Several flows of Pahoehoe will be described presently overlying the ash, some of them from the Mohokea depression itself.

5. More or less connected with them are several discharges of aa.

6. Last of all, I should not fail to recall the disastrous earthquakes of 1868, whose epicentrum lay in the vicinity of this caldera. No more severe shocks have ever been experienced since the country has been settled by people of European descent. The quakes were observed at Kona, Kahuka, Waiohinu, Kau, Kilauea, and Hilo. All were severe, but the greatest devastation was wrought in the vicinity of Mohokea. Can it be that the seat of the seismic disturbances lay beneath Mohokea? The

chief discharge of lava was on the flank of Mauna Loa several miles west of Mohokea, and there was another from Kilauea in the opposite direction.

Eruptions of Lava from the lower Levels

The Mauna Loa flows may be classified by the altitudes at which the discharges take place. First, those from the upper part of the dome, as those of 1843, 1852, 1855, 1859, 1880, 1889, and 1899, starting from 9,000 to 11,000 feet above the sea. They are strongly characterized by a hydrostatic connection with the central pit at Mokuaweoweo. The lava comes from the extreme depth under the ocean to the caldera, and after two or three days' stay at the summit it breaks out quietly on the side of the mountain, and may flow to the sealevel in the course of several months. The other class, as represented by the flows of 1868 and 1887, shows first the same supply of lava at the summit, but breaks out low down, 3,000 or 6,000 feet above the sea, with violent earthquakes, those lowest down being the most frightful, and the lava issues tumultuously through long fissures. I can now add quite a number to the list of those that have issued from the lower level. They were prehistoric, so that it is impossible to connect them with manifestations in Mokuaweoweo.

In this class I will include several undefined aa eruptions east of Pahala. The first poses on the government map as having been erupted in 1823, and is quite near Kilauea. As there represented, I think it is made up of three eruptions. The first, prehistoric, 9,300 feet above the sea, near Puu ula ula, well shown on E. D. Baldwin's unpublished survey. This probably was of the first class, originating high up. The second part must have been of the kind originating low down, starting near the line between the Mauna Loa and Kilauea areas, at an elevation of more than 3,000 feet. A macadamized road now crosses it diagonally for as much as 6 miles, and it is certainly of prehistoric age. It has moved southwest with very little fall. The third part originated from Kilauea in 1823, and is probably the only area that came to the surface at that time. It was visited by Reverend Mr Ellis in 1823 and is described in his journal.*

The second mention is that of one or more ancient flows between the Halfway House and Pahala. Some of them cover the yellow ash beds, others are much older, or at least they had their day before the deposit

* I have been unable to discover from whence the compilers of the map could have derived the theory of the connection between the upper eruption of Mauna Loa and that from Kilauea in 1823. None of the Survey officers, past or present, can state whence the information was obtained.

of ash. Some of the recent exposures show a beautifully smooth pahoehoe, which when protected by an earthy covering really recall, by their freshness and smoothness, glaciated surfaces in more northern climes. Mr Mann, one of the lunas at Hilea, told me he had seen five different lava flows belonging to this later period to the east of Pahala. They have a thickness of 28 feet. This is in the vicinity of the mud flow of 1868.

Thirdly, extensive aa flows, which have originated in the depressed area of Mohokea east of Puu Enuhe.

The fourth eruption is aa from between Puu Enuhe and Makawao.

The fifth eruption is made up of at least three aa flows and the later pahoehoe between Hilea and Hanuapo.

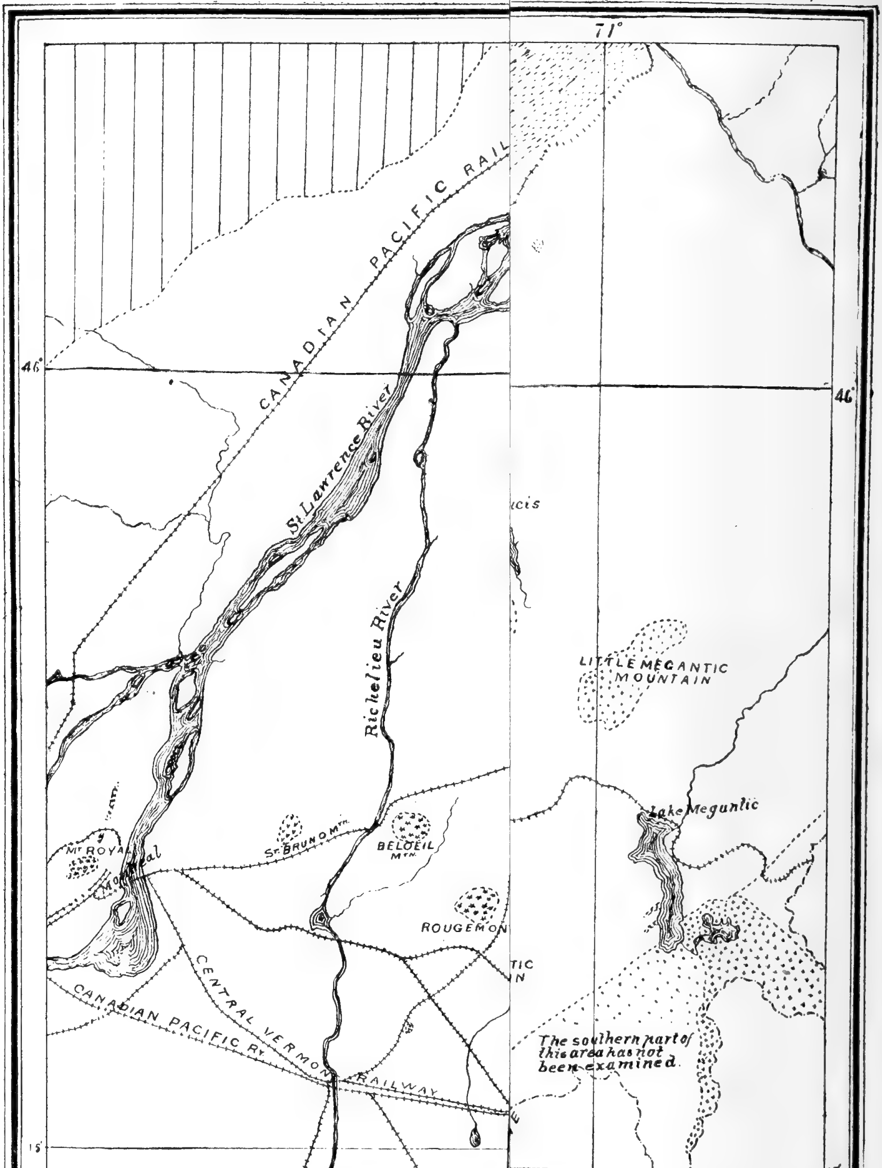
In the sixth area there are some undetermined factors. Undoubtedly there were discharges on the Kahuku promontory between Honuapo and the 1868 flow, but we are sure of those of 1868 and 1887, which have been fully described. Farther north I observed from the steamer half a dozen of these short flows, of very modern aspect, before reaching Cape Honumalo. Here commences the steeper slopes of the Kona district for a distance of 60 miles. Much of the way the 1,000-foot contour is only a mile back from the shore, and it rises nearly as rapidly to 3,000 and 4,000 feet. I observed fresh black lava flows at Hoopaloa, Naupoopoo, and Kailua. It was dark as I sailed from Hoopaloa to Naupoopoo, so it was not possible to say what number of flows might exist between those two localities. Most of this bluff belonged to the sheets originating from Mauna Loa.

Hualalei

After reaching the Hualalei district the land slopes more gradually to the sea, and the finest of all our illustrations of the low level eruptions is the only eruption from Hualalei of which we have an historic record. It started from the level of 1,800 feet and flowed to the sea in 1801, spreading out very much laterally. The distance between the extreme points on the shore exceeds the length of the flow. Three other very distinct earlier but prehistoric flows are delineated on the north side of Hualalei, starting from points 3,700 to 6,000 feet above the sealevel. As Hualalei reaches only to 8,269 feet, at least the highest of these flows may belong to the other variety of discharges.

Hualalei was visited by Menzies, the botanist, in 1794, as stated in the narrative of the voyage of Vancouver. The same gentleman made the attempt to climb Mauna Loa, but for some unknown reason the historian has not had this later report of Menzies printed. There is an excellent

sketch of the summit crater of Hualalei, with a brief description of the ascent, in the Vancouver narrative. It seems clear, therefore, that there have been many eruptions from the lower levels of the Mauna Loa dome on the south and southwest sides. Whether any or all of them had direct connection with Mokuaweoweo, like those of 1868 and 1887, can not be known, but the description of Mohokea sustains the early formed impression, that it represents an independent caldera.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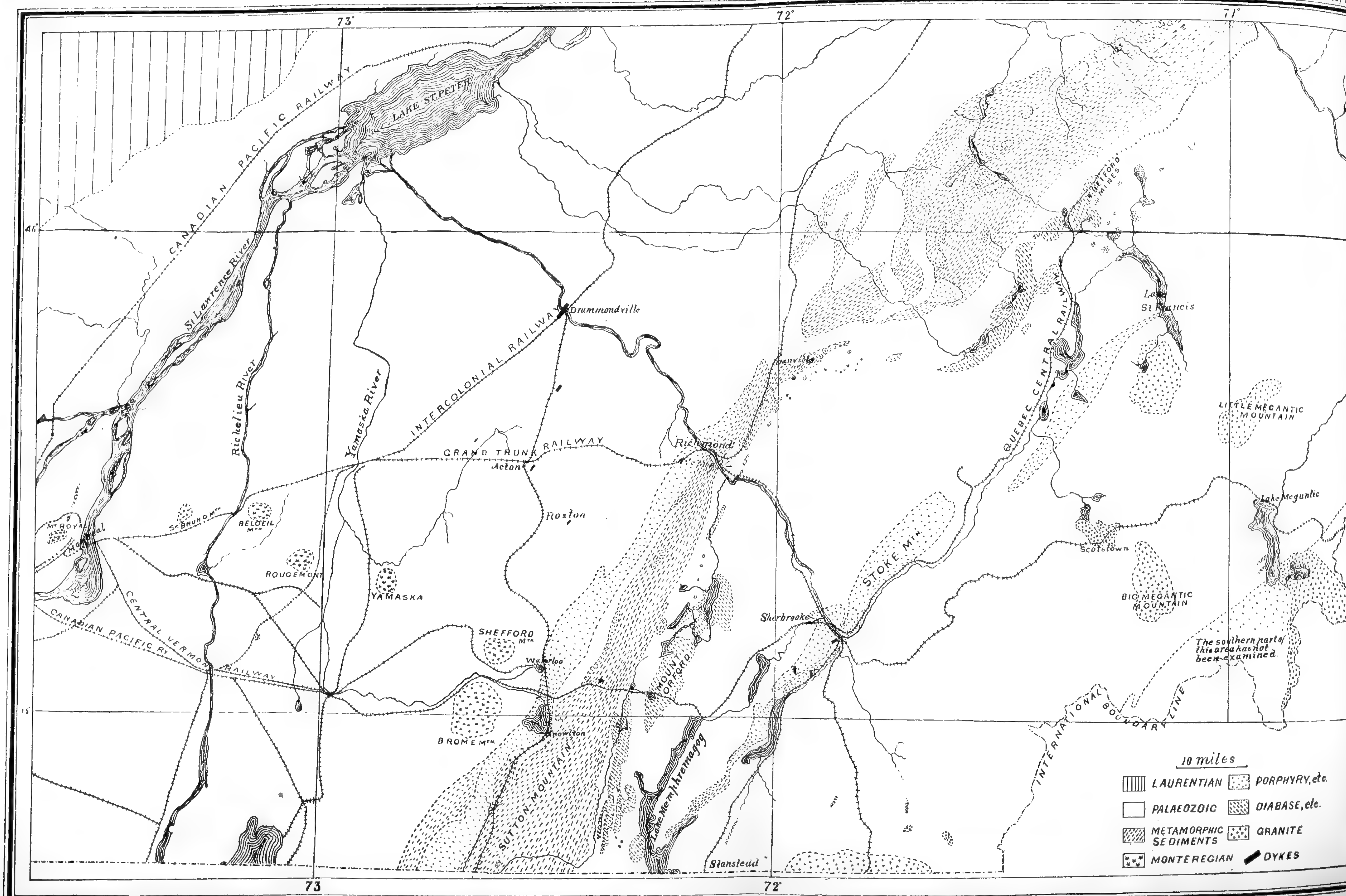
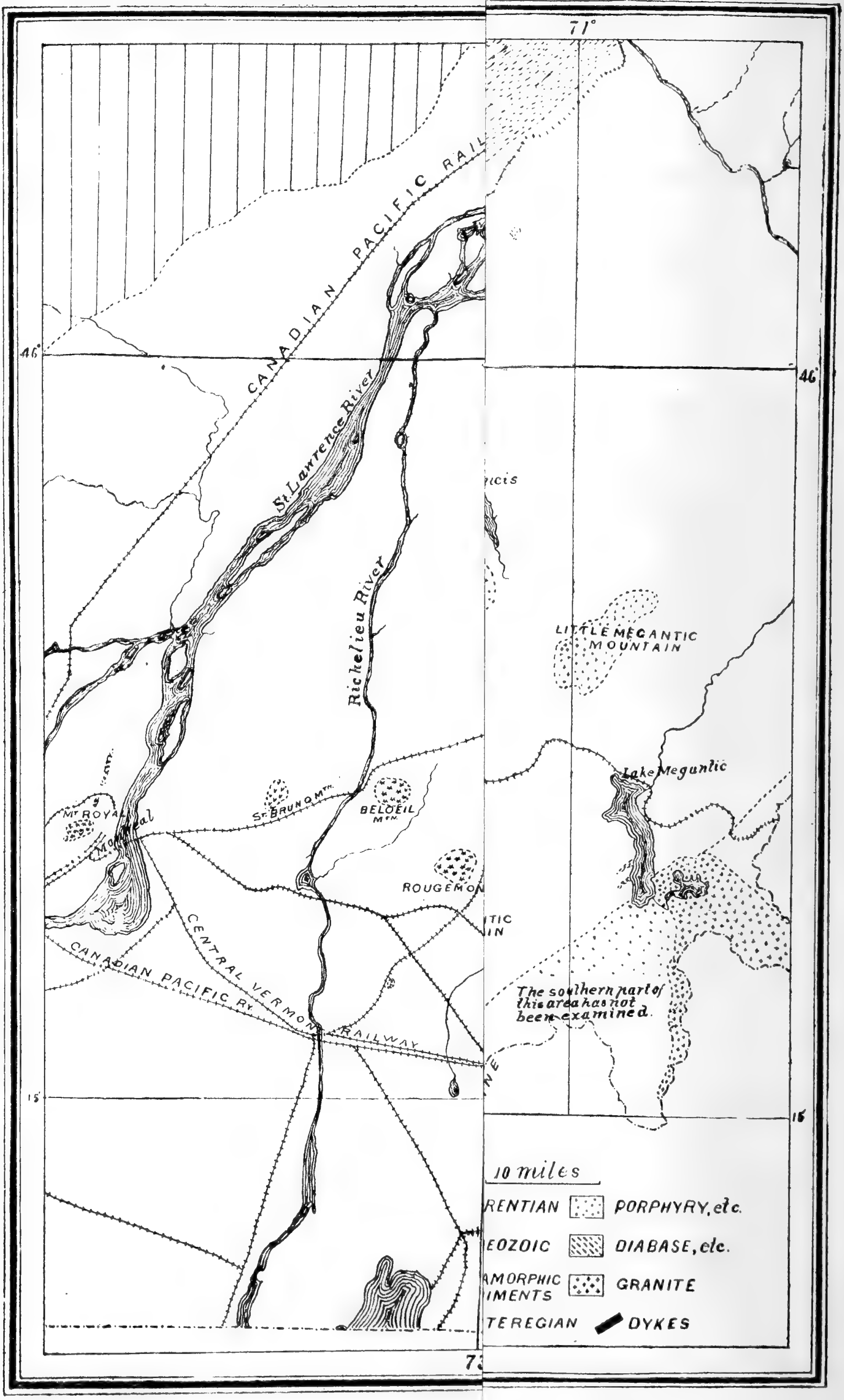


MAP OF SOUTHERN QUEBEC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IGNEOUS ROCKS OF THE EASTERN TOWNSHIPS OF QUEBEC

BY JOHN A. DRESSER

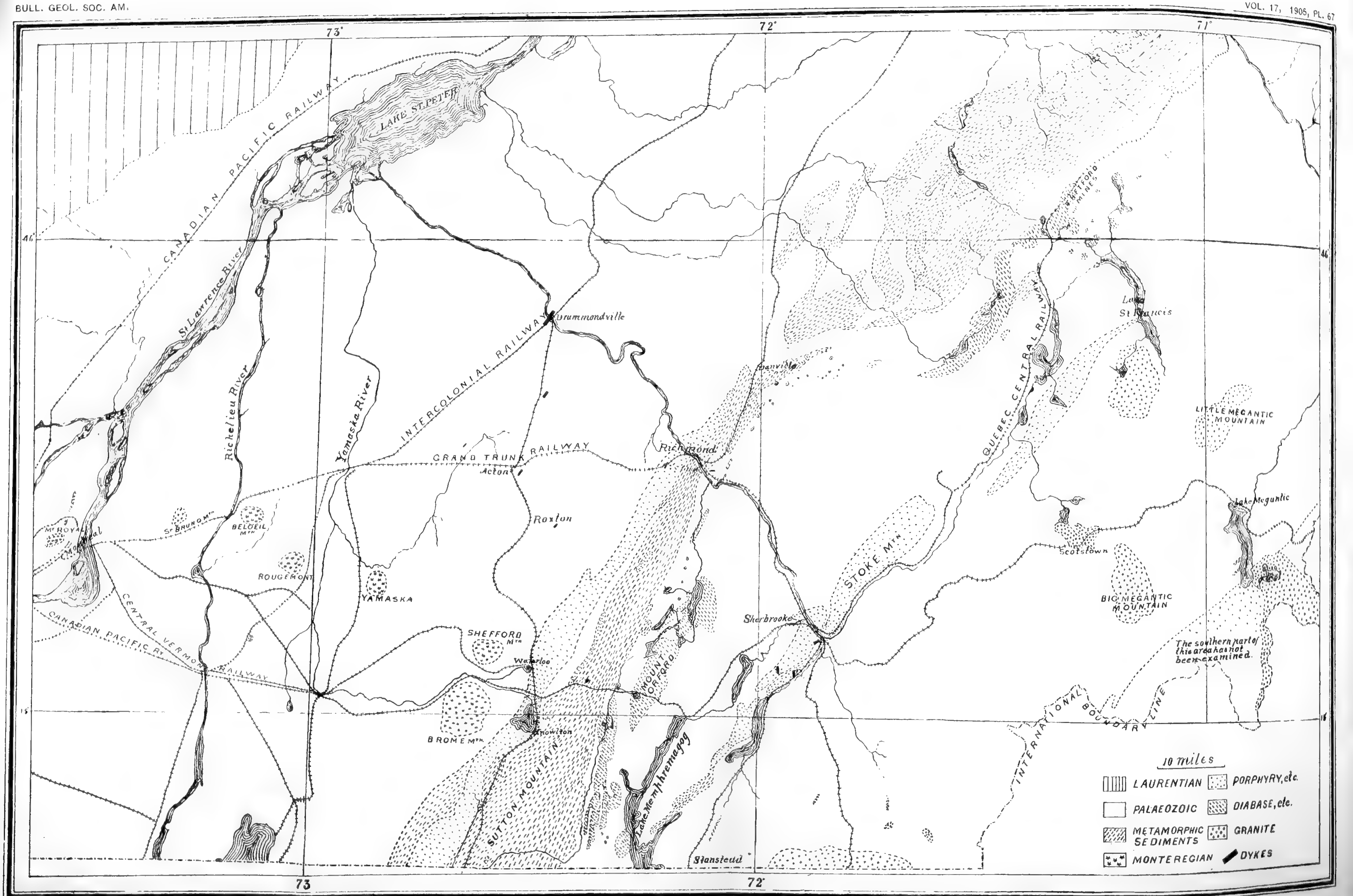
(*Read before the Society December 27, 1905*)

CONTENTS.

AREA DEFINED

That portion of the province of Quebec which has been affected by the Appalachian uplift lies wholly to the south of the Saint Lawrence river. It comprises two somewhat distinct parts, the mountainous region of the Gaspé peninsula along the lower Saint Lawrence and the hilly country from the Chaudiere river to the international boundary line between the province of Quebec and the states of Maine, New Hampshire, and Vermont. The interval between the two portions is marked only by a subsidence in the Appalachian hills southeast of the city of Quebec.

The second of these two areas is commonly designated as the "Eastern townships." Being less easily accessible, on account of its hilly character as well as its position, and also less desirable otherwise for settlement, this region was not surveyed until some thirty years after the cession of Canada to England. It was then divided into townships approx-



MAP OF SOUTHERN QUEBEC

imately square, and it was further subdivided into ranges and lots, according to the English method, instead of being formed into seigniories and parishes, after the old French mode of survey.

Geography of the Region

The general trend of the hills of the eastern townships is a northeasterly one, conforming to the direction of the Appalachian folding, the successive ridges growing higher as they are more remote from the Saint Lawrence valley. The principal rivers, such as the Yamaska, Saint Francis, Nicolet, Becancour, and Chaudiere, cross these hills about at right angles to their course and drain the region into the Saint Lawrence.

The tributaries of these rivers take their direction from the Appalachian folds and generally flow in either northeast or southwest courses. The tributaries are therefore subsequent to the Appalachian hills, while the main rivers are either antecedent to the later stages of that uplift or have been superposed upon these older rocks by the extensive denudation of the region; hence the tributaries are commonly much younger than the main rivers. From these facts and also since the course of chief glacial action has been parallel to the valleys of the principal rivers and transverse to the tributaries, it results that many of the latter empty into the former by falls and rapids. The water which these furnish has given rise to several manufacturing centers, as the city of Sherbrooke, where the Magog falls into the Saint Francis, and the town of Windsor Mills, at the junction of the Wattopekak with the same river. The principal rivers thus give cross-sections of the region, while the tributaries usually afford much less information regarding the underlying rock.

General Geology

With the exception of a few small outliers of Devonian, the sedimentary rocks of the Eastern townships are now considered to be pre-Silurian in age. Silurian strata occur a short distance to the north of the district in question and small outliers may be found within it, but thus far none have been definitely determined. To the Cambro-Silurian have been assigned certain of the limestones, the calcareous and ferruginous slates; to the Cambrian, part of the quartzites, graywacke, and clay slates; while similar rocks, with the exception of the clay slates, are referred to pre-Cambrian, as well as the large areas of slate characterized by the presence of chlorite and epidote.

Igneous rocks are found to underlie the earliest sediments, to be intercalated among them, and to be intrusive through even the latest.

Altered volcanics of both acid and basic types are the oldest, while closely associated with them are large areas of stratified rock which are thought to be in part at least much altered tuffs. Serpentines occur among the earliest sediments and probably also cut others of somewhat later age. The diabases and later gabbro-diorites, which are closely associated with the serpentines in position, as well as the granites, which lie to the southeast of the Appalachian ridges, and the syenitic rocks of the Monteregian hills to the northwest, are later in age than any of the sediments. Still later than these are the dikes of camptonite, diabase, and bostonite which cut any of the rocks already mentioned and are themselves little altered in character or disturbed in position.

Extreme metamorphism has obscured or totally obliterated much of the fossil evidence which the sedimentary rocks might otherwise have furnished, while such fossil evidence as remains is rendered less useful for precise correlation by the peculiar conditions under which these sediments have probably been deposited. They have accordingly been designated in geological nomenclature as the Quebec group.* The group of rocks thus named by Logan and Billings was considered by them to be equivalent to the calciferous and chazy formations in part. Subsequently, however, Selwyn and Ells distinguished within the area assigned to the Quebec group the measures now mapped as pre-Cambrian, showed much of the supposed Silurian to be Cambro-Silurian, and classed the greater part of the remaining rocks as Cambrian.

The pre-Cambrian comprises three main ridges, which are the principal physiographic features of the eastern townships, namely, Sutton mountain, Stoke mountain, and the Boundary Line hills. These ridges, which are roughly parallel, run in a northeasterly course, as determined by the Appalachian folding, and are themselves about 25 miles apart between the Saint Francis and the Chaudiere rivers.

Previous geological Research

The rocks composing the ridges just referred to were named argillites, sandstones, chloritic and nacreous schists, and slates, in the first investigations of the Geological Survey under Sir W. E. Logan and Dr T. S. Hunt. In stratigraphical arrangement these ridges were supposed to be synclinal troughs which had resisted denudation better than the intervening strata.

This view was first questioned by Hunt on stratigraphic grounds, and later by Selwyn, both on stratigraphic and lithologic evidence. Doctor

* Sir W. E. Logan: Geology of Canada, 1863 and later.

Selwyn reached the conclusion that these folded ridges were anticlines, not synclines, and held that the rocks composing them were older than the Quebec group and consequently formed no part of it. The results of the subsequent investigations of Doctor Ells substantiated this view.

The first igneous rocks recognized in the Eastern townships were the granites of Stanstead and Megantic, the syenitic rocks of Monteregian hills, Brome and Shefford, and the Gabbro-diorites of Brompton, Orford, and Ham. These were described at some length in the Geology of Canada, 1863, and had been previously discussed by Hunt.

Both Hunt and Logan regarded the serpentines as altered sediments and correlated them stratigraphically with the dolomites, in view of their magnesian contents. Doctor Selwyn seems to have been the first to point out the probable origin of the serpentines, and also suggested that the stratigraphic questions then under discussion were complicated by the fact that some of the other highly metamorphosed rocks were in reality disguised volcanics. A suite of specimens of doubtful rocks submitted by him to Dr F. D. Adams* proved the serpentines to be altered igneous rocks generally of the peridotite class, the so-called diorite to be diabases and allied rocks, and some of the other highly altered rocks of the region to be of sedimentary origin.

The reexamination of the areal geology of the district which was necessitated by this information was entrusted to Dr R. W. Ells, the results of whose investigations appear in the annual reports of the years 1886, 1887, and 1894, and in the maps which accompany them.

In these maps the crystalline belts of Sutton and of Stoke mountain are represented as pre-Cambrian in age, and an area along the international boundary line is included in the same horizon. The sediments intervening are assigned to the Cambrian and Cambro-Silurian, with the exception of some very minor areas, which, as has been said, were found to have been occupied with remnants of Devonian and possibly of Silurian measures. The serpentines are included with the igneous rocks and the occurrences of "diorite" are shown to be more numerous than appeared in the earlier maps. The great body of the pre-Cambrian, however, remained among the sedimentary rocks.

Besides these investigations a few independent papers have been published on the region.

In 1876 Sir J. William Dawson discussed the mode of entombment of certain fossils, referring especially to localities in the Eastern townships. Some of the occurrences of fossils thus mentioned are of essential importance to these investigations.

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* Annual Report, Geological Survey of Canada, 1880-1881-1882.

In 1879 Dr T. Sterry Hunt discussed the structure of the region in the American Geologist, under the title "The Quebec Group in Geology."

In 1882 Dr A. R. C. Selwyn first outlined his views of the structure and general lithology of the Quebec Group in an address before the Royal Society of Canada.*

In 1902 the present writer showed that important parts of the pre-Cambrian are composed of volcanic rocks which by their extreme alteration had been previously mistaken for sediments. Their relation to other occurrences of similar rocks in the Appalachians was suggested and their place in the series described by the late G. H. Williams was pointed out.†

The pre-Cambrian copper-bearing Volcanics

The physiographic structure of the Eastern townships, it has been said, depends on three ridges of pre-Cambrian rock which are in the form of rather narrow belts about 25 miles apart, running parallel to the axes of the Appalachian mountains. These ridges which appear above the intervening sediments and later intrusives are the crests of once buried mountain ranges, now partially uncovered. Here and there outlying remnants of sedimentary rock still rest on them.

One of the belts appears for only a relatively short distance along the boundary line between the province of Quebec and the state of Maine. It occurs in the townships of Emberton, Chesham, Clinton, Woburn, Ditchfield, and Spalding. From its proximity to the lake of that name, it may be designated the Lake Megantic area.

The second crosses the Saint Francis river between the city of Sherbrooke and the village of Lennoxville, and is commonly referred to as the Ascot or Stoke Mountain belt. It may be traced from the foot of Owlshead mountain and lake Memphremagog, through parts of the townships of Stanstead, Hatley, Ascot, Ascot Corner, Stoke, Dudswell, Weedon, and Stratford. The similar rock at the Gilbert River gold mines, in the seigniory of Delery, on the east side of the Chaudiere river, undoubtedly belongs to this belt.

The third of these belts, which crosses the Saint Francis river near the town of Richmond 25 miles northwest of the last, is generally known as the Sutton Mountain belt. This is the largest and longest of the three, as far as is at present known. While the Stoke belt is nowhere more than 5 miles in width, that of Sutton is quite 20 miles wide at the Vermont

* Transactions of the Royal Society of Canada, 1882.

† Transactions of the Canadian Mining Institute, Montreal, March 12, 1902. American Journal of Science, July, 1902.

boundary line. It has a considerable development in the counties of Sutton, Brome, Shefford, Richmond, Wolfe, Arthabaska, Megantic, Beauce, Dorchester, and probably extends also into Bellchasse and Montmagny—that is, to a point at least 140 miles from the boundary of the state of Vermont.

The rocks of the Sutton Mountain area were described by Logan* as "chloritic, micaceous and epidotic rocks. Towards the province line," he continues,

these are of a slaty character and various shades of color, from dark bluish-green or blackish-green to ash grey. The green bands are more abundant than the grey, and both have occasionally a talcoid lustre. The grey bands appear to derive their color from a large amount of very fine grains of quartz which are uniformly mixed with chlorite. These beds often contain certain nodules of white granular quartz, and crystalline pistachio-green epidote sometimes several inches in diameter, and frequently elongated in parallel directions. The two minerals are often in separate nodules, but as often are intermixed; in the latter case the epidote is generally within the quartz. In the grey bands, fine blackish-green lines of chlorite often run parallel to one another, but these are contorted by the nodules of quartz and epidote, with which orthoclase feldspar is sometimes associated.

Radiated actinolite often occurs in the rocks together with asbestos in short parallel veins, which are found cutting the epidote in the direction in which the nodules are elongated, and occasionally between the layers of slate. Crystals of specular and magnetic oxide of iron are abundant in the chloritic and epidotic bands, the magnetic species being more frequent where the chlorite prevails.

Near the Saint Francis, nodules of an epidotic character are richly disseminated through the chief part of these chloritic strata, some of the nodules being six, eight and even ten inches in diameter. Some of the bands hold small portions of finely granular quartz which occasionally swell into beds of white quartzite of some importance, while many of the strata assume the aspect of fine quartzose curglomerates or coarse sandstones with a chloritic base.

Regarding the rocks of the Stoke belt, Logan writes:†

The rocks of this group here at the base of Owls Head mountain, branching off from a range of hills which come up from Vermont into Canada, take a northeasterly direction, and crossing Memphremagog lake run from the township of Stanstead through Stoke to Weedon, and constitute the Stoke mountains, which are bounded on each side by more recent strata just mentioned. The average breadth occupied by the Quebec group in these hills seldom exceeds 2 or 3 miles, except in Ascot and Stoke. On the Saint Francis in the former township, through the influence of these undulations, the Quebec rocks have a transverse measure of 7 miles extending from the vicinity of Lennox-

* Geology of Canada, 1863, p. 246.
† Geology of Canada, p. 252.

ville to the northwest corner of the township, and in Stoke they present two parallel ranges included in a breadth of about 5 miles.

In this range of hills the strata consist chiefly of chloritic rocks in harder and softer bands, the softer and more schistose constituting chlorite slates, while the harder may be termed chloritic sandstones. With these are associated micaceous and nacreous slates often presenting a very quartzose character, and thin layers of agalmatolite of a somewhat fibrous texture are sometimes met with. Some of the micaceous and nacreous slates are very fine grained, and on the south side of the range afford excellent whetstones and hones. Many of the whetstone beds appear to be micaceous slates passing into argillite. Some bands of the slate are studded with chloritoid, and in Sherbrooke they enclose a bed of blood-red Jasper, passing into a siliceous, red hematite, and another of a somewhat siliceous conglomerate.

In the same neighborhood the nacreous slates are marked by the occurrence of copper pyrites, containing a little gold and silver, in a gangue of white quartz running with the stratification. The chloritic slates are often marked by iron and copper pyrites; and on Haskell hill on the eighth lot of the eighth range of Ascot, a band of slate five feet wide, holds such a quantity of copper ore as to give promise of a profitable mine.

Selwyn suggested that slates might be volcanic as well as sedimentary, but subsequent reports added nothing to the lithologic description of these rocks.

The rocks of these belts consist of two parts, one of which is stratified and the other unstratified. The latter is a volcanic rock, finely crystalline and of both acid and basic phases. Quartz porphyry and andesite or diabase would originally have been the extreme types. Some of basic phases are altered to serpentine and all have been highly metamorphosed. It is only by very detailed field study, together with microscopic examination, that the volcanic character of some of these rocks has been ascertained.

Associated with these are stratified rocks of similar material, but which have an original clastic structure. Part contains bands of nearly pure chlorite, abundant quartz veins, and much iron ore. These are thought to be stratified tuffs, while other rocks, generally more siliceous, as chloritic sandstones and graywackes, are probably true sediments.

Although highly altered, the volcanics of this series show their original characters in localities in which the deformation has been least. The acid phase of the rock is largely a quartz porphyry. A specimen from the hanging wall of the Silver Star mine at Suffield is light gray in color, and on the weathered surface the quartz phenocrysts are quite conspicuous. Owing to the bleaching of the base, the rock has commonly been mistaken for quartzite or a species of sandstone. The following is an analysis by Mr M. F. Connor, of the Geological Survey of Canada, of a

specimen of the essentially similar rock from the quarry at Sherbrooke, which furnishes road metal for the streets of that city:

SiO_2	70.37
TiO_2	.17
Al_2O_3	11.27
F_2O_3	.80
FeO	2.58
MgO	2.03
CaO	2.31
Na_2O	2.63
K_2O	1.86
CO_2	3.60
H_2O	1.96
	99.58

The large amount of CO_2 shows the rock to be too far altered to be satisfactorily classified according to the quantitative classification.

Neglecting CO_2, however, the following is the norm:

Q	38.34
or	11.12
ab	22.01
an	11.40
C	.82
hyp	8.00
mt	1.16
il	.30

Class I, Persalane.
Order 3, Columbare.
Rang 3, Riesenase.
Subrang 4, —— dosodic.

In the thin-section it is found to be a porphyritic rock with a finely crystalline base, which contains phenocrysts of quartz and feldspar. The latter are both orthoclase and plagioclase, the former being the more abundant.

Small rod-like bodies of colorless mica are present in the rock, as well as irregular areas of a rhombohedral carbonate which is apparently dolomite.

Near Lennoxville, on the line of the Canadian Pacific railway, the rock becomes a granite porphyry, differing from the rock just described chiefly in the more advanced character of its crystallization. Farther eastward, where this belt is somewhat wider, the central portion becomes still more coarsely crystalline and passes from quartz porphyry at the margin to

granite porphyry, and finally to a porphyritic granite toward the interior. The latter is the rock of Bald peak and of other principal hills of the central portion of the Stoke Mountain area, as well as a part of the pre-Cambrian of Weedon. The basic portion is less well preserved, and its original characters can not be as precisely determined, as there are probably no original bisilicates now present. The decomposition products and traces of the original structure indicate that the rock had, in some cases at least, the characters of diabase, while in others it was probably a porphyrite or andesite, rich in ferromagnesian constituents. Areas of serpentine are occasionally found within the district occupied by this rock which pass by sharp transition into hornblende porphyrite. While the alteration to serpentine seems to be complete, no part of the orginal rock being left, the serpentine has a somewhat different appearance from that derived from the olivine-rich rocks of the larger serpentine areas of the adjoining district. It is distinguished by the "grating" or "bar" structure of serpentine derived from hornblende or augite instead of the "mesh" forms resulting from the alteration of olivine. Small seams of asbestos occur in this serpentine, but although several of the areas have been prospected, no important deposit of that mineral seems to have been found in them.

The acid and the basic phases of these volcanics are, however, products of separate irruptions, but are due to sharply defined magmatic differentiation. This is well shown in several of the streams which drain the southern part of Stoke mountain, notably on Rowe's brook. The rocks may be considered as products of a single flow or of one flow for each bolt. In the Sutton belt and, so far as is known, in the Lake Megantic area also, there is evidence of no later volcanic action. In the Stoke belt, however, later dikes occur somewhat frequently, but they are chiefly of the camptonite and diabase classes. They cut the adjacent Trenton sediments, and so belong to a series of rocks to be described later, rather than to those of the present class, as they are not of pre-Cambrian age.

The pre-Cambrian volcanics are apparently closely related to those of South mountain, Pennsylvania, and other known localities to the southward, and form a link of the more westerly of the two chains of early volcanics that were described by the late G. H. Williams.*

Possible pre-Cambrian Sediments

Of the stratified rocks which are most closely associated with the volcanics referred to above the extremely chloritic portions are probably

* Journal of Geology, January, February, 1894. See also "Ancient volcanics of South mountain," by F. Bascom, Bull. U. S. Geol. Survey, no. 136.

ancient tuff beds, or at least are composed of fragmental volcanic material, and so are pyroclastic rocks. In the present degree of alteration they do not differ essentially from certain portions of basic rocks just described. Besides, these are siliceous rocks, quartzites, graywackes, and chloritic sandstones, which are possibly true sediments. With them are frequent beds of dolomite, the origin of which seems a matter of doubt. The rock is frequently found resting on a basic trap, filling pit-holes and interstices within it and inclosing fragments of it. In other cases the rock passes by rather gradual transition into quartzose dolomite in masses of considerable extent. At the Eustis mine the portion of the country rock known to the miners as the "green rock" is of this type. Even in thin-sections small areas of dolomite appear, sometimes inclosing small quartz crystals and indicating the secondary nature of the dolomite.

Certain of the micaceous chloritic slates also contain sufficient amount of dolomite to cause a slight effervescence with hydrochloric acid when heated.

Along the Saint Francis river the Sutton belt is some 7 miles in its extreme width, including nearly 2 miles of recognized Trenton measures within it. A detailed study shows the volcanics at the base with dolomite, quartzite, and gray mica-chist, in ascending order. Within the dolomite are certain peculiar inclusions of a bluish gray limestone which has been largely crystallized by intense regional metamorphism. One of these inclusions, however, contains fossil evidence of its Calciferous-Chazy age. It is therefore demonstrated that in this part at least the Sutton Mountain belt contains no pre-Cambrian clastics.

The following is the section referred to crossing the pre-Cambrian near Saint Francis river.

The line of section* extends between lots 10 and 27, in range 12, in the township of Cleveland, and is about a mile and a half east of Saint Francis river and approximately parallel to it. The direction of the section is north 38 degrees west, magnetic. The adjacent rocks at both north and south have been recently mapped in the reports of the Geological Survey as Cambrian, the black limestone number 3 of the section as Trenton, and the rest as pre-Cambrian.

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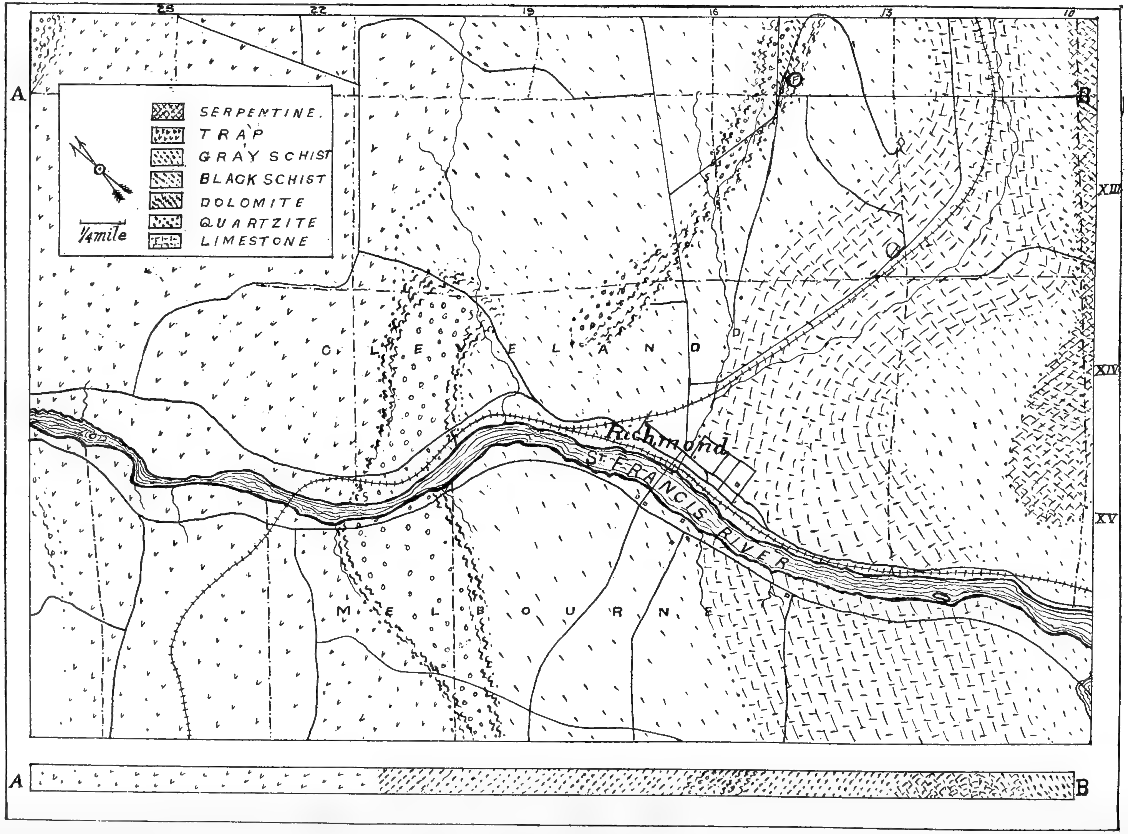
* This locality was considered by Logan to furnish the key to the structure of the Quebec group. Hither he returned after severing his connection with the Geological Survey, and spent four seasons in making a detailed map of the district for several miles on either side of this section. This map, which seems to have been ready for engraving at the time of his death, was unfortunately never published.



MAP AND SECTION, SUTTON MOUNTAIN SERIES, NEAR RICHMOND, QUEBEC

Section

	Feet
1. Black mica-schist	100
2. Gray mica-schist	1,320
3. Black limestone	2,800
4. Gray mica-schist	4,590
5. Micaceous dolomite	300
6. Black mica-schist	600
7. Quartzite	180
8. Micaceous dolomite	60
9. Gray mica-schist	7,360
Total sediments	17,310
10. Amygdaloidal trap	12,540
Total igneous	12,540

Their distribution can be seen by the accompanying map (figure 1).

The contacts of the sedimentary rocks with one another in this section are of the nature of transitions, suggesting that no marked dislocation or important time-break occurs between them. The graphitic limestone passes upward into mica-chist by an almost insensible gradation, as can be well seen along either bank of Saint Francis river. Still better evidence is to be found in the banks of Eddy brook, a small stream in the village of Melbourne, which has cut a postglacial gorge near its outlet into the Saint Francis river. Here in a height of about 30 feet the rock passes from typical black limestone in the bed of the stream to dark mica-schist at the top of the northern bank. The mica-schist can be seen in several places to pass gradually into micaceous dolomite, and the latter into quartzite. It accordingly seems justifiable to conclude that the sedimentary rocks of this section belong to a single cycle of deposition.

The igneous rocks are older than the sediments. All the rocks north of the black limestone, number 4 to number 9, dip toward the northwest, and those on the south side of the limestone, numbers 1 and 2, dip in the opposite direction, or about southeast. The limestone thus apparently forms the axis of an anticline, and so must be the oldest of the stratified of the section. This is the view of the structure that was held by Logan, while Ells considers the limestone to be of much more recent formation than the other rocks of the section, and to have been brought into its present position by "an intricate system of folding and faults." The former placed all these rocks in the Quebec group of Calciferous-Chazy, while the latter regards the limestone as lower Trenton and all the other rocks as pre-Cambrian.

It is an apparent fact that the dolomite schists do not belong to the pre-Cambrian, for they carry crinoid stems and other fossil evidences of

their Calciferous or Chazy age. The fossils, which are referred to by the late Sir William Dawson in an article entitled "On Palæozoic fossils mineralized with silicates,"* occur in lot 14, range XII, of the township of Cleveland, about 300 yards east of the Healy schoolhouse.

In this article the fossils were referred to as of Lower Silurian age, and the genera Stenopora and Ptilodictya are mentioned, but no more definite description seems to have been yet published.

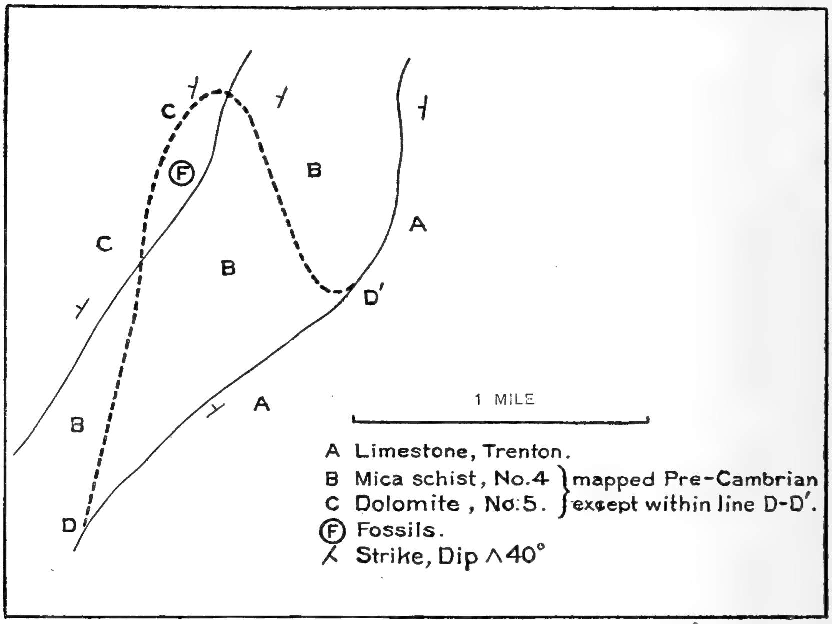


FIGURE 1.—*Lots 13, 14, 15, Ranges XII and XIII, Township of Cleveland*

The importance of this occurrence of fossils seems to have been lost sight of in the more recent maps of the Geological Survey, for it has been erroneously connected with the black limestone (number 13 in the above section), which has long been known to be fossiliferous and which lies three-quarters of a mile distant. Thus, in the Sherbrooke and the Montreal sheets of the Eastern Townships map,† the locality of these fossils is included in the Trenton area by a peculiar indentation, D-D′ (figure 1), in the part colored pre-Cambrian, the boundaries of which are thus made to cross the actual stratification of the rocks. The part of the dolomite B immediately surrounding the locality of the fossils and the intervening mica-schists are accordingly colored Trenton in lots 13, 14, and 15, while

* Quarterly Jonrnal, Geological Society, London, Eng-, February, 1879, pp. 60–62.
† Geological Survey of Canada, 1886-1894.

they, B-B, are elsewhere mapped as pre-Cambrian in either direction along the strike.

The black limestone (number 3) seems to be quite as highly folded and contorted as the older rocks of the section. On the whole, there appears to the writer no reason to believe that there was any great time-break in the deposition of the sedimentary rocks of this section, or that they are not products of a single cycle of deposition.

The order of deposition of these rocks appears to be as follows, in ascending order:

1. Black limestone, with black mica-schist as its marginal or shallow-water equivalent.
2. Quartzite, quartzose, and micaceous dolomites, which were chiefly deposited in the northern part of the section and barely extend to the northern side of the present exposure of the black limestone.
3. Gray mica-schist covered the entire trough between the pre-existing igneous ridges. The gray schists probably owe their greater thickness toward the northern end of the section to the fact that the Cambro-Silurian transgression came from the north and possibly also to isoclinal folding.

As it thus seems certain that the Sutton series contains no pre-Cambrian clastics in the vicinity of Saint Francis river, it is consequently possible, if not probable, that all the clastic rocks of this series, throughout the district, are altered members of the Quebec group, as in this section.

The volcanics are the oldest rocks of the region, and from their lithologic resemblance to the pre-Cambrian rocks of Pennsylvania and other parts of the Appalachians they are thought to be of that age. However, there is as yet no direct proof of this.

The overlying sediments are always much altered. In some cases the alteration would seem to indicate that these sediments are older than the comparatively unaltered rocks of the basins between the metamorphic ridges, but in other cases they can be traced continuously to rocks of undoubted Cambro-Silurian age. While the different degrees of alteration may in all cases be due to differences of position or of susceptibility to metamorphism of the various rocks, it is not necessarily the case. Accordingly the question of the existence of pre-Cambrian sediments in the Eastern townships must yet remain an open one.*

The Serpentines and Diabases

A little to the east of the Sutton ridge and parallel to it there is a

* J. A. Dresser: American Journal of Science, January, 1906. "A study in the metamorphic rocks of the St. Francis valley, Quebec."

series of irregular hills which are instrusive through most of the other rocks of the region, generally Paleozoic sediments. They occur notably in the counties of Brome, Sherbrooke, Richmond, Wolfe, Megantic, and probably in Dorchester, and are likewise known to reappear in the Gaspé highlands. Among them are the Bolton mountains, Owls head, Orford, Ham, and Adstock mountains. The rocks composing them are serpentines, diabase, gabbro-diorites, with frequent or smaller masses of hornblende granite and occasionally much smaller bodies of porphyrite. Of these rocks the serpentine seems to be in all cases the oldest, being cut by intrusions of the other, and probably it is older than the paleozoic sediments. The diabases and gabbro-diorites, which are phases of the same magma, form the greater part of all these hills. They are later in age than the serpentines through which they are commonly intrusive. The hornblende granite in some instances is distinctly intruded through the serpentines, but in one case at least, the Big Ham mountain, it seems unmistakably to have been differentiated from the parent magma of that rock *in situ.*

The porphyrite is of limited occurrence, but at Shipton pinnacle, where it is best seen, it seems to cut the serpentine. It generally occurs as the matrix of a band of breccia seldom exceeding 300 yards in width that is frequently found along the southern edge of the serpentine belt. As far as it has been studied, it is found to be a quartzless porphyrite containing a little hornblende as the only ferromagnesian constituent.

Mount Orford (2,860 feet) is the best known as well as the largest of the gabbro-diorite and diabase hills. It has an area of not less than 20 square miles and an average height above the surrounding country of 1,000 feet. It comprises two main divisions which give the following cross-section, measured westward along the line of the Canadian Pacific railway near Miletta: Diabase or gabbro-diorite, 7,837 feet; graywacke, 165 feet; serpentine, 577 feet; sandstone, 82 feet; serpentine, 1,567 feet. This section is bounded by sedimentary rocks on either side. The rock of the first and greater mass is a uniform green color and shows gray grains on a freshly broken surface. Quartz veins are common, and the joint, plants and seams are often studded with small quartz crystals. Patches of epidote sometimes as much as a foot in diameter are numerous. The texture of the rock becomes finer toward the outer edge and also toward the top of the mountain, where the cooling of the igneous mass has taken place more rapidly.

In thin-section this rock, which is exceedingly altered, shows plagioclase feldspar with aggregates of the pyroxenic decomposition products, whose relation one to another indicates that the rock had the structure

of a diabase. In the coarse and central parts of the mountain the mineral olivine appears. The rock has the mineral composition of diorite; but the hornblende is secondary and the rock therefore becomes a gabbro-diorite. The two rocks are apparently differentiation products of a single volcanic output.*

Analyses by Hunt† show the composition of the altered gabbro-diorite and diabase mass under the head of diorites to be as follows:

		I	II	III
I. Diorite	SiO_2	63.40	63.60	63.43
Brompton lake	Al_2O_3	12.70	14.20	14.20
Orford, range XVI, lot 2	FeO	4.23	1.92	1.54
II. Diorite	MgO	3.37	6.84	2.35
Saint Francois de Beauce	CaO	7.50	4.37	5.51
III. Granodiorite, Butte county	K_2O	.13	5.09	2.19
Lassen peak, California:				
	Na_2O	7.95	4.13	3.49
	H_2O	.40	.70	1.65
	...	.....	.....	.87
		99.68	100.85	99.80

Owls head (2,465 feet) is situated on the west side of lake Memphremagog, 16 miles south of mount Orford, which stands at the northern end of the same lake. The level of this lake is about 682 feet above sealevel.

The rock at the eastern base along the lake shore is a common basic phase of the pre-Cambrian volcanics. On the west side the adjacent rocks are sedimentary. Between these the mass of the mountain has been intruded. It consists, as far as yet known, of extremely altered diabase, which was first determined by Doctor Adams. Sugarloaf, the name by which a continuation of the Owls head mass toward Orford is generally known, has been also shown by Doctor Adams to be similar in composition.‡

Besides Orford, Owls head, and Sugarloaf, there are several hills along this line, presumably similar in character. These are Hogs back, between the two mountains last mentioned; Hawk and Bear mountains at the south of Owls head, and Carbuncle and other hills at the north of Orford. So far as known, these hills are similar to Orford and Owls head in general structure as well as in the character of the rocks composing them. Fifty miles to the northeastward from Orford, Big Ham

* J. A. Dresser: American Geologist, January, 1901.
† Report Geological Survey of Canada, 1853, *a*1.
‡ Report Geological Survey of Canada, 1880-1881-1882, part A, appendix.

mountain appears as the next prominent point along the serpentine belt, although that belt is almost continuous throughout the distance. The mountain rises 1,400 feet above the neighboring land, or 2,400 feet above mean sealevel.

This mountain, as far as known, is a mass of much altered diabase. Near the eastern edge of the summit the diabase passes into a rock intermediate between hornblende granite and diorite, which may be tentatively classed as a granodiorite. The transition is a rather sharp one, a distance of a few yards only separating typical specimens of the two rocks. The granodiorite seems to form only a small body, and is probably the residual filling of the neck of the volcano which gave rise to the mass of the mountain.

Moose mountain, in the township of Cranbourne, beyond the northeastern limit of this map, is thought to belong to this series, although there is not much definite evidence concerning it yet available. A specimen from a spur of the mountain in the township of Frampton is a porphyrite—a not uncommon marginal phase of these rocks—and as Doctor Ells reports the mountain to be intrusive in its relation to the sediments of the district, it may apparently be safely correlated with the present series.

Rocks very similar to those of Orford have been described from Adstock mountain, and also from the township of Potton, by Dr F. D. Adams.* Doctor Adams found a specimen from the summit of Adstock to be a diabase, and one from another part of the same mountain to be a diorite, both being much altered rocks. Concerning the latter he writes:

It is rather coarsely crystalline, massive, and of a grayish-green color, and is composed of hornblende and plagioclase. The hornblende is green, or, in some places, brownish in color, and is distinctly pleochroic. . . . It is often twinned. Much of the hornblende is decomposed to chlorite. In many cases the alteration appears to pass through an intermediate stage in which the hornblende assumes a very finely fibrous appearance. The fibers are generally approximately parallel, but do not as a general rule extinguish simultaneously. Individual fibers can often be seen to have an extinction inclined at a small angle to their longer axes. Some of these fibrous grains show a distinct biaxial figure. The plagioclase is dull from incipient decomposition, but generally shows well defined polysynthetic twins, of which two sets are frequently present crossing one another. Although the two minerals have interfered with each other in crystallizing both show good crystal forms. The feldspar is perhaps upon the whole the better crystallized of the two. The fibrous hornblende is found everywhere to be mixed with chlorite.

* Op. cit.

The igneous origin of the serpentine was also first pointed out by Doctor Adams in the same publication. In a specimen from Melbourne the rock was found to be wholly reduced to serpentine, with the exception of a few grains of bastite or other mineral derived from rhombic pyroxene. In specimens from townships of Ham remnants of the primary olivine were also found.

The following analysis of serpentine of the Eastern townships are taken from the Geology of Canada, 1863:

	Orford.	Ham.	Bolton
Silica	40.30	43.40	43.70
Magnesia	39.07	40.00	40.68
Nickel oxide	.20	.....	.....
Ferrous iron	7.02	3.60	3.51
Water	13.14	13.00	12.45
	100.00	100.00	100.34

Hornblende granite also occurs within this belt and is commonly intrusive through the serpentine. In other parts it seems to form an acid portion rather sharply differentiated from the magma of the parent rock of the serpentine. It has been described by Doctor Adams* as composed esentially of quartz, orthoclase, plagioclase, and hornblende, with a little titanic ore. It is also noted as showing a peculiar alteration of the hornblende. Where this mineral comes in contact with the quartz it displays a development of fibrous forms terminating in tufts of fine needles running into the quartz; opposed to this marginal facies when in contact with quartz, hornblende displays an ordinary even edge when in contact with the fieldspar.

Dikes of this rock in cutting the serpentine are considered by miners to be indicative of the occurrence of the good asbestos. Whether the fracturing of the serpentine accompanying the intrusion of the granite has in any way furnished lines of weakness for the formation of asbestos veins has not yet been established.

Serpentine apparently quite different in origin occurs at several places within the porphyry-andesite belt already described. Here within a distance of 10 to 20 feet well exposed rock may be traced from a quartz porphyrite to serpentine carrying narrow veins of asbestos. Such occurrences are found in the townships of Ham, Leeds, and several other places within the volcanic belt. So far as yet known, none of these are of large extent. That in Leeds is probably half a mile in length. The importance lies, however, in showing the range of magmatic differentiation, and con-

* Op. cit.

sequently that the quartz-porphyry and serpentine are differentiates of a single original magma. As these are the extremes of chemical composition among the various rocks of the region, the probability of all being differentiation products of a single primary magma is quite apparent.

The Granites

The granites of the Eastern townships occupy six principal areas, none of comparatively great extent. They form the granite masses of Stanstead, Hereford mountain, Big Megantic mountain, Little Megantic mountain, a small area on the east side of lake Memphremagog, and another near Danville. There are probably numerous other small occurrences in this district, but it is noticeable that all of the granites lie to the south of the volcanics of the Sutton ridge.

None of the granite bodies have as yet been studied in detail, but all are believed to be intrusive through Lower Silurian sediments, and are thought to be of late Devonian age. The extensive quarries at Stanstead have made the economic importance of that occurrence well in the province of Quebec, where Stanstead granite is largely used for structural purposes. A specimen of this granite has been described by Dr F. D. Adams,* and shown to consist essentially of orthoclase, quartz, and biotite, with accessory amounts of microcline and plagioclase and secondary muscovite and epidote.

Of Hereford mountain nothing definite is known, save that its proximity to Stanstead and the generally similar appearance of the rock in the hand specimen suggest its close relation to that body. Its contact with the sediments is undoubtedly intrusive.

Even less is known of the Big and the Little Megantic mountains. The material in the talus slopes of the former is a very acid granite.

The granite from Scotstown contains pyroxene, in addition to biotite and muscovite, as ferromagnesian constituents.

The granite near lake Memphremagog is also of the type of that of Stanstead.

Near Danville there is a small body of granite whose relations to the surrounding rocks have not been ascertained, nor has it received any detailed study. Biotite is the only dark constituent that is noticeable in the hand specimen. It is stated in the Geology of Canada (page 811) that it furnished part of the material for the Grand Trunk Railway bridge which crosses the Nicolet river in the vicinity.

* "Description of a series of thin sections of typical rocks," by Frank D. Adams, Ph. D., F. G. S., Montreal, 1896.

The granite from the quarries at Stanstead shows an incipient cataclastic structure in the microscopic section, and in the mass a somewhat distinct foliation, known by the quarrymen as the "rift." This structure is apparently due to dynamic metamorphism and shows the granites to have shared in the folding of the Appalachian uplift, and consequently to have been intruded before that movement had entirely ceased. As dikes of adjacent granite masses cut Devonian (Lower Helderberg) strata on the shore of lake Memphremagog, these intrusives are thought to be of late Devonian age.

The later Dikes

A series of dikes of much later age than any of the rocks hitherto described is widely distributed throughout the region. They are comparatively fresh in composition and little disturbed in position. Camptonite, diabase, and bostonite are the chief rock types represented among them.

A camptonite at Richmond was found by the writer* to consist of hornblende and plagioclase, with accessory magnetite and apatite. A little leucoxene and small aggregates of chlorite, serpentine, and calcite indicate that some degree of decomposition has already begun in the rock.

The hornblende is brown in color and shows the extinction angle, $\mathfrak{c} \wedge \mathfrak{c}$, was observed to be as high as 17 degrees.

This dike, which is about three feet wide, cuts lower Trenton limestone, which had been greatly folded and distorted prior to the injection of the dike. One or two other smaller dikes occur in the vicinity, and a small hill near by is thought to be underlain by some igneous rock.

In the vicinity of Sherbrooke, 25 miles south of this locality, dikes are known to occur in several localities.

Near the line of the Canadian Pacific railway, in the northern outskirts of the village of Lennoxville, there is a camptonite dike very similar to the above. It cuts both pre-Cambrian volcanics and Trenton slates.

At the Howard mine, Ascot, a dike of olivine-diabase cuts pre-Cambrian eruptions.

In a paper entitled "Camptonites and other intrusives about lake Memphremagog,"† Mr V. F. Marsters discusses a large number of dikes in the Lake Memphremagog basin, distinguishing the granites, etcetera,

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* J. A. Dresser: A hornblende lamprophyre dyke at Richmond, Province of Quebec. Canadian Record of Science, Montreal, January, 1901.

† American Geology, July, 1895.

connected with the intrusions off McGoons point, already mentioned, from Camptonites and allied dike rocks.

Between Roxton, in the county of Shefford, and Saint Nicholas, in the county of Lotbinière, a distance of more than 100 miles, there are several occurrences of intrusive rock in lower Paleozoic strata. It is little known except in connection with copper deposits in the region, which it seems invariably to accompany. It is found at Roxton, Acton, Upton, Durham, Wickham, Drummondville, Nelson, Saint Flavien, Saint Apollinaire, and Saint Nicholas, and seems to form a series of dikes in a comparatively narrow belt throughout this distance. The dikes vary in width from a few inches to a thousand feet, or even more, and run parallel to the length of the belt in which they occur—that is, in a northeast-southwesterly direction.

At Roxton there is an intrusive, a light colored rock of the trachyte class, but in most of its occurrences the intrusive is a diabase, and is commonly amygdaloidal.

The largest exposures are at Saint Flavien, Nelson, and Drummondville. At Saint Flavien the intrusion is nearly a quarter of a mile wide, and appears to be a wide dike, extending for a distance of about a mile through the country. Similar rock appears at Saint Apollinaire, 7 miles distant.

These are the principal rock exposures. It is a level district, covered with a heavy mantle of drift. The rock is amygdaloidal in many parts, the amygydules being most commonly filled with calcite; but sometimes epidote and chlorite or quartz form the filling material. Copper frequently occurs in this rock, as at Roxton, Nelson, and Wendover, near Drummondville. In other places, as at Acton, Upton, and Wickham, the copper occurs in the ektomorphic contact zone of the inclosing rock. The exposure at Nelson is smaller than that at Saint Flavien, while that at Drummondville is apparently quite as large.

It is thus described by Logan:*

The greenish sandstones on the Saint Francis are intersected by several dikes of diorite, the courses of which are in a general way down the stream. The rock of the fall at Drummondville appears also to be a diorite and is of a gray or greenish color; it probably belongs to the stratification and is not known to have any connection with the dikes. It has a breadth of about half a mile, and some parts are porphyritic from the presence of small crystals of light, greenish fieldspar, while others are amygdaloidal, holding small portions of a light and calcspar and occasional nodules of agate. Much of it bears the aspect of breccia, in which fragments of the diorite are held together by a close grained but highly crystalline calcareous cement, approaching in color the

* Geology of Canada, 1863, p. 243.

general mass of the rock. The rock bears a resemblance to that of Saint Flavien, of which it may be a continuation, and like it is highly cupriferous.

So far as yet examined, some half dozen specimens, the diorite of the above description proves to be a fine-grained diabase. The diabase forms two bands crossing Saint Francis river here, one having a width of a quarter of a mile and the other of about 50 feet. The distance between them is rather more than a quarter of a mile and is occupied by very dark graphite limestone and greenish gray sedimentary slates. What appears to be devitrified glass was found along the contact of the diabase and the latter rock. These rocks have been here mentioned under the head of "Later dikes" because of their lithological similarity to known dikes and the absence as yet of satisfactory proof that they are not themselves also of that class. This entire series offers an excellent field for an interesting and important detailed investigation.

The Monteregian Hills

This name, which has now gained general currency in geological nomenclature, was proposed by Dr F. D. Adams in 1903* to designate a series of volcanic hills which crosses the Saint Lawrence valley in the southwestern part of the province of Quebec. These hills, which are eight in number, are of volcanic origin, either stocks or laccolites. They owe their present relief to differential erosion, and consequently are hills of the butte type.

Six of the eight hills form a nearly east and west line, standing about 10 miles apart. In order from west to east, they are mount Royal, at the foot of which stands the city of Montreal (Mont Royal); Montarville or Saint Bruno, Beloeil or Saint Hilaire, Rougemont, Yamaska, and Shefford. The remaining stand at the south of this line, Brome being 2½ miles from Shefford and mount Johnson 6 miles from Rougemont.

The lithological characters of these hills are such as to show them to be a distinct petrographical province, and to bear little, if any, relation to the rocks hitherto described in this article. In every hill there is a large development of essexite, which frequently passes into theralite, and in every one which has been studied in detail an alkali syenite, such as nordmarkite, pulaskite,. or nepheline-syenite. Their general features may be presented in the following summary form:

Mount Royal has an area of about 2 square miles and attains an elevation 769.6 feet above mean sealevel. The altitude of the Grand Trunk

* Journal of Geology, volume xi, no. 3, "The Monteregian hills, a Canadian petrographic province."

railway at Bonaventure depot, Montreal, at the base of the mountain, is 48.33 feet.

The mountain consists of two distinct intrusions, the first and larger being essexite, the second nepheline-syenite. In structure it is thought to be a volcanic neck, probably with laccolitic offshoots. It has may dikes and sheets of bostonite, camptonite, tinguaite, and allied rocks.

A breccia near by has an ash rock for its matrix and contains, among other included fragments, some blocks of Devonian age.

It is now under investigation by Professors Harrington and Adams.

The area of Montarville, or Saint Bruno mountain, is approximately 2.64 square miles. The average of several aneroid readings shows its altitude to be 563 feet—that is, 466 feet above the Grand Trunk Railway station of Saint Bruno.

It consists of a single intrusion and is composed entirely of essexite except for a small area of half an acre. This is occupied by a rock of the pulaskite type, which has been formed by differentiation *in situ* from the essexite magma. A few dikes of camptonite are found.*

Beloeil, or Saint Hilaire mountain, has an area of some 4 square miles and an altitude of 1,437 feet above sealevel, or 1,350 feet above the railway near its base. It consists of a single intrusion, differentiated to form essexite and a nepheline-rich syenite. The former rock makes up the greater part of the mountain.

A few dikes of camptonite are to be seen.†

Rougemont occupies about 6 square miles and reaches a height of 1,400 feet, or 1,250 feet above the surrounding plain. As far as yet known, it consists of one intrusion of essexite. No dikes are known.

Mount Johnson, the smallest of the series, has an extent of .422 of a square mile. Its altitude is 875 feet, giving it an elevation of 720 feet above the neighboring village of Saint Gregoire. It is a volcanic neck, differentiated from a core of essexite to a rim of pulaskite, with an intermediate phase (andose).‡

There are only a few dikes.

Yamaska hill covers some 5½ square miles. It greatest altitude is about 1,500 feet, nearly 1,300 feet above the surrounding country.

It has been found to consist of a single intrusion which has differentiated *in situ* into rocks of the essexite-nepheline-syenite series. Dikes are few.§

Shefford mountain occupies nearly 9 square miles and rises to a height of 1,600 feet above sealevel, or 1,200 feet above the surrounding country.

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* J. A. Dresser: Summary Report, Geological Survey of Canada, 1905.
† O. E. Le Roy: Summary Report, Geological Survey of Canada, 1901.
‡ F. D. Adams in Journal of Geology, vol. xi, no. 3.
§ G. A. Young: Summary report, Geological Survey of Canada, 1903.

It consists of essexite, nordmarkite, and pulaskite, the first comprising about half of the mountain. Each rock is the result of a separate intrusion. Dikes are very numerous and belong to the bostonite-camptonite series. The mountain is a laccolite.*

Brome mountain is 100 feet lower than the neighboring mountain of Shefford and occupies about 30 square miles.

It consists of essexite, alkali-syenite, and a small body of tinguaite. It has been formed by two or possibly three separate irruptions and is probably part of the laccolite of Shefford, which is only 2½ miles distant. It has very few dikes.†

Chemical Analyses of Type Rocks from the Monteregian Hills

The following are analyses of rocks from the Monteregian hills:

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2	48.69	48.85	53.15	44.00	65.43	61.77	57.44	59.96	55.68
Al_2O_3	17.91	19.38	17.64	27.73	16.96	18.05	19.43	19.12	20.39
Fe_2O_3	3.09	4.29	3.10	2.36	1.55	1.77	1.69	1.85	2.10
FeO	6.41	4.94	4.65	3.90	1.53	1.75	2.70	1.73	1.95
MgO	3.06	2.00	2.94	2.30	1.36	1.54	1.16	.65	.80
CaO	7.30	7.98	5.66	13.94	.22	.89	2.66	2.24	1.92
Na_2O	5.95	5.44	5.00	2.36	5.95	6.83	6.48	6.98	9.18
K_2O	2.56	1.91	3.10	.45	5.36	5.21	4.28	4.91	5.34
TiO_2	2.71	2.47	1.52	1.90	.16	.74	1.97	.66	.60
P_2O_5	1.11	1.23	.65	.20	.02	.15	.60	.14	.06
MnO	.15	.19	.46	.08	.40	.08	.25	.49	.31
Cl	.....	.....	.07	.....	.04	.....	.....	.....	.....
H_2O	.95	.68	1.10	.80	.82	1.10	1.03	1.10	1.50
	99.36	100.02	99.84	100.01	99.78	99.97	99.69	100.17	99.83

I. Essexite (Essexose) Mount Johnson.
II. Essexite (Andose) Mount Johnson.
III. Essexite (Akerose) Shefford.
IV. Essexite (Hessose) Brome.
V. Nordmarkite (Nordmarkase) Shefford.
VI. Nordmarkite (Nordmarkase) Brome.
VII. Pulaskite (Laurvikose) Mount Johnson.
VIII. Pulaskite (Laurvikose) Shefford.
IX. Tinguaite (Laurdalose) Brome.

Genetic Relations of the igneous Rocks

A better knowledge of the igneous rocks of the Eastern townships, especially of the granites and diabases, is necessary before their genetic

* J. A. Dresser in American Geologist, October, 1901, and in Geological Survey of Canada, 1899, part L.

† J. A. Dresser in American Journal of Science, May, 1904.

relations can be satisfactorily discussed; yet certain general relations may now be deduced, and these conclusions, it is hoped, may be amplified and more precisely applied at some later time, when all the rocks in question have become better known.

In general terms it may be said that those rocks of a definite district belong to the same province,* whose phases in their nearest approach to one another do not differ more widely than the various differentiates of any single mass. Thus the porphyry-andesite series differs in its acid phase from the granites, as far as the latter are known, chiefly in degree of crystallization, not in composition. The more basic phase of the old volcanics, as has been shown, passes into a rock which has altered into serpentine by differentiation *in situ*. Hence this oldest group seems to form a connecting link between the granites on one hand and the diabase serpentines, etcetera, on the other, while the hornblende granites similarly connect the diabases and normal granites. Accordingly, those three groups form part of a single petrographic province, according to the definitions quoted above; but the Monteregian rocks appear more distinct throughout the quite extensive range of variation within themselves. The individual hills differ from one another in a comparatively small degree; also their distinctive characteristics are not found in any measure in the other groups of rocks mentioned. Should a detailed study of the granites show that within them are differentiated portions of more basic rocks—for example, should nepheline syenite be found in association with them, as it has been found in some cases in the Hastings district by Doctors Adams and Barlow,† they would then appear as an acid extreme toward the east of the Monteregian series. But this has not been done, nor is there at present any valid reason for expecting such phenomena to be found. While the Monteregians appear at regular intervals at upward of 10 miles across the plain, no rocks of a consanguineous type have been found to the east of Shefford mountain, although a careful examination has been made in that direction throughout the district wherever igneous rocks are known to occur. In the later dikes an indication of rocks of the Monteregian type exists; for while it is conceivable that almost any rock might be differentiated in small amounts from almost any magma, it is the most common relationship to find camptonite and bostonite types differentiated from highly alkaline magma such as that of the Monteregian rocks; but the wide distribution of these dikes and their relatively small amount make them less important factors in considering the limits

* Dr H. S. Washington: "Petrographic province of Essex county, Massachusetts." Journal of Geology, vols. vi and vii.

† Summary Report, Geological Survey of Canada, 1898.

of the petrographic provinces. Thus, while camptonites and bostonites may occur in many places to the east of the Sutton Mountain anticline and diabase far to the west of it, as Drummondville or Saint Flavien, they rather illustrate what Professor Pirsson * has recently called the progression of rock types than the extension of the boundary of either of the two distinct groups of rocks mentioned. It would therefore seem that the rocks of the Monteregian hills differ from the other rocks described in this article more widely than any of those from one another—that is, that the difference is a generic rather than a specific one; hence the relation could be best defined as that of two contiguous provinces rather than as parts of one province, even in the larger sense.

The study of the consanguinity of rocks tends toward the hypothesis that the interior of the earth may be regarded as containing a single magma of uniform character which by process of differentiation within the crust of the earth, or during the process of extrusion, or during the process of cooling after extrusion gives rise to all classes of igneous rock. This is the extreme view of the origin of different species of igneous rocks by the process of differentiation. Partly in opposition to this is that known as the assimilation theory, which supposes igneous rocks to owe many of their present differences to the older rocks with which they have come in contact and by which they have been modified. This theory could scarcely receive, under any circumstances, such wide application as that just assigned to the differentiation theory, namely, that all rocks have come from a universal common magma and are differentiated only by the rock material with which they come in contact; nor could it be counted a directly essential character in large extrusive volcanic outputs; but in consideration of intrusive rocks where the invading lava may for long periods of time have been slowly taking in and dissolving the surrounding rock material, the process of magmatic stoping † may have made the assimilation factor an important one in the modification of igneous rocks.

The Monteregian hills are all intrusive and are comparatively small igneous masses; they have penetrated strata of different mineralogical and chemical composition. Thus the Hudson River mudstones, Trenton limestones, the graphitic limestone, and black slates of the Farnham and Phillipsburg series, as well as the quartz mica-schists of the Sillery, have been penetrated by these rocks without producing any material change in the rocks themselves beyond a generally well marked endomorphic con-

* American Journal of Science, July, 1905.

† Dr R. A. Daly: "On the mechanics of igneous intrusives." Am. Jour. Sci., 1903; ibid., August, 1905.

tact zone. Moreover, the sedimentary rocks through which the granites and the diabase series have been intruded are generally very similar to those surrounding the Monteregian hills; in fact, the Hudson River shales are the only rocks of the latter region not found in the former. Hence it would seem that, whatever the cause may be of the primary magmatic differentiation, the magma which gave rise to the Monteregian hills was primarily different from that which produced the other rocks discussed, with the partial exception already mentioned, of the later dikes.

Summary

In summary it may be said that the rocks of southeastern Quebec present two petrographical provinces, and their differences are due to primary differentiation—that is, to differences in the original magmas.

I. (*a*) Porphyry-andesite series, extrusive and probably of pre-Cambrian age.

(*b*) The diabase-serpentine group, inclusive in a large measure, ranging in age from early Cambrian to late Silurian.

(*c*) The granites, intrusive, late Devonian age.

(*d*) Between these and the next province, in a measure bridging over the gap between them or at least indicating that the extreme limit of each has been reached, are the later dikes.

II. The second province comprises properly only that unique group, the Monteregian hills.

Addendum

For the completion of the investigation which has been briefly outlined in this paper a large amount of field and laboratory work is yet necessary, much of which has an economic importance that is not less than its value to pure science. The later dikes are very little known, and yet the occurrence of important deposits of copper in the northern part of the district occupied by them has been known for fifty years. The granites are a geologic unit concerning which we have very little knowledge and of which correspondingly little use is made, while the pyrrhotites of the diabase series promise economic results perhaps no less important than the asbestos and chromic iron deposits, which also await detailed petrographic investigation.

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LITHOLOGICAL CHARACTERS OF THE VIRGINIA GRANITES*

BY THOMAS LEONARD WATSON

(Presented by title before the Society December 29, 1905)

CONTENTS.

INTRODUCTION

The general excellence of the Virginia granites as a building and monumental stone is well established in the commercial world. Notwith-

*The writer is indebted to Dr H. Ries for taking the photographs from which the half-tone of this paper were made.

standing this fact no published account of the geology of these rocks has been made, so far as the writer is aware. A part of two seasons has been devoted by the writer to a study of the Virginia granites in the field and in the laboratory, and it is with the hope of contributing to the knowledge of the geology of these rocks that prompted the preparation of this paper.

The Virginia Piedmont Region

GEOLOGY

The Piedmont province in Virginia forms a part of the eastern crystalline area which extends southwestward from New York to northern central Alabama. It extends eastward from the Blue ridge to the western margin of the Coastal plain, and it widens southward. Lack of systematic study of the Virginia Piedmont region forbids more than a general description of its geology at this time. The rocks composing the region are the oldest in the state, and, excepting the areas of Jura-Trias, they are all crystalline. Rogers mapped the crystalline rocks of the region as Archean, but more recent studies reveal the fact that a part of them are as late as Ordovician in age.

The rocks comprise sedimentary and igneous masses so greatly altered from metamorphism that many of them bear but slight resemblance to the original masses. The region is made up of a complex of schists, gneisses, and granites, with, in places, minor interfoliations of slates, quartzites, and limestones. This complex is further intersected by intrusions of basic eruptive rocks belonging, so far as they have been studied, to the diabasic, dioritic, and gabbroic types. To the east of Danville, in the extreme southern part of the region, is an area of altered andesite which extends into North Carolina and is regarded as pre-Cambrian in age.

Over the eastern, northern, central, and southern parts of the Piedmont are areas of Jura-Trias shale, sandstone, and conglomerate. The northern and eastern areas of these rocks are quite extensive.

DISTRIBUTION OF THE GRANITES

The granites are limited to the crystalline area described above and comprise both massive and schistose types. The schistose granites or gneisses have very wide distribution throughout the Virginia Piedmont, forming one of the dominant rock types. The principal areas of producing massive granites are distributed in a north-south direction near the eastern border of the Piedmont plain. They include (1) the Petersburg area, (2) the Richmond area, and (3) the Fredericksburg area.

In addition to these there are several minor areas, chief among which are those of Fairfax, Prince Edward, Fluvanna, and Goochland counties.

The massive granites will be described under the following types: The Richmond-Fredericksburg, light gray; the Richmond-Fredericksburg, dark blue; the Fredericksburg, light gray; the Falls Church and Annandale types, and the Unakite type.

Mineral Composition of the Granites

Conforming with well known granites elsewhere, the Virginia rocks are mixtures of feldspar and quartz, with biotite as the third essential component, in the most important areas. Muscovite in subordinate amount usually accompanies the biotite in all the granitic areas of the state, and it becomes a principal component, replacing biotite in the granite of the Hazel Run area west of Fredericksburg. Hornblende is an important constituent in only a part of the granites of the Falls Church area southwest of Washington, and it is almost unknown in the granites of the other areas. It is essentially absent from the most economically important granites of the state.

In the unique variety of granite known as unakite, occurring near Luray, in Page and Madison counties, in the Blue ridge, and near Troutdale, in Grayson county, epidote is a principal constituent and the ferromagnesian silicates nearly or entirely fail. The epidote is wholly a secondary constituent.

The dominant species of feldspar in the Virginia granites is usually orthoclase, though in many instances microcline or plagioclase may equal or even exceed orthoclase in amount. One of the most striking features in the mineralogical constitution of these rocks is their usual richness in both microcline and plagioclase, especially the latter. Both of these feldspars, however, are subject to much variation, and in a few thin-sections examined their poverty was a noticeable feature. It seems probable that a part of the microcline in the Virginia rocks has developed in part from orthoclase by pressure metamorphism.

Besides the above minerals, there occur apatite, zircon, sphene, magnetite, and occasionally some other minerals.

Kinds of Granite

Conforming with the granites of the southeastern Atlantic states in general, the granites of Virginia vary in structure from massive to schistose, and in texture from even-granular to porphyritic rocks. On this basis three types of the rocks are distinguished: (1) Massive even-

granular granites, (2) porphyritic granites, and (3) schistose granites or granite-gneisses. The granite-gneisses were derived from the massive granites, from which they principally differ in the pronounced schistose structure secondarily induced by dynamic metamorphism.

Based on mineral composition, the Virginia granites are divisible into the following leading types: (1) Biotite granite, which usually carries a little muscovite in addition to the biotite, and under which a majority of the granites of the state may be grouped, including the Richmond-Petersburg areas, and most of the Fredericksburg area; (2) muscovite granite, of which the Hazel Run area one mile west of Fredericksburg is the only typical representative yet known; (3) hornblende-biotite granite, represented by a part of the granites occurring southwest of Washington, in the Falls Church area in Fairfax county; and (4) epidote granite, unakite, of which there are only two known localities.

In addition to these, pegmatite, coarse crystallizations of quartz and feldspar with subordinate mica, in dike-like form, abundantly penetrate the finer granites and associated crystalline rocks over much of the Piedmont region. Aplite is represented only in the granite of the Richmond area, and here principally on the western border of the Richmond basin, near Midlothian.

Even-granular Granites

INTRODUCTORY STATEMENT

The granites distributed along the fall-line in the eastern part of the Piedmont region in the vicinity of Richmond, Petersburg, and Fredericksburg are the most important economically in the state and they best illustrate the types of mica-granite. Three types are here represented based on differences which are best brought out under the individual descriptions below. The three types are: (1) The Richmond-Petersburg light gray, (2) the Richmond-Fredericksburg dark blue gray, and (3) the Fredericksburg light gray.

To these, two additional types must be added from other parts of the state. These include the Falls Church dark gray hornblende-biotite type and the yellowish green and pink epidote type known as unakite.

PETROGRAPHY OF THE GRANITES

The Richmond-Petersburg light gray granite.—This type of granite has been quarried for many years in the vicinity of Richmond and Petersburg. It extends over parts of three counties, namely, Dinwiddie, Chesterfield, and Henrico. It is a biotite-granite, frequently containing a

little muscovite, and it consists of anhedra which range in size from 1 to 5 millimeters. Variation in the size of anhedra here given is a noticeable feature of this type in the quarries opened around the cities of Richmond and Petersburg. The principal minerals are quartz, orthoclase, microcline, plagioclase near oligoclase, biotite, a little muscovite, sphene, magnetite, apatite, and zircon. The usual alteration minerals occur, chief among which are chlorite, epidote, muscovite, and kaolin. These are the normal minerals in granite.

Rutile needles are abundant in some of the quartz. Granophyric intergrowths of the quartz and feldspars are very abundant in the thin-sections studied, indicating overlap in the period of formation of these minerals. The quartz intergrowth is not restricted to any single species of feldspar, but it seems to be of about equal development in the orthoclase, microcline, and plagioclase. Orthoclase is usually the dominant feldspar, but microcline or plagioclase may either equal or even exceed it in amount. An important feature in the mineral composition of these rocks is the nearly constant large amount of plagioclase present. It occurs in large stout laths and is always characterized by the polysynthetic twinning striæ in basal sections. Extinction angles measured against the twinning striæ usually indicate a plagioclase near oligoclase. Twinning on the Carlsbad law is very common among the feldspars, both in thin-sections and in hand specimens of the rock. Microperthitic intergrowths of the feldspars are freely developed in most of the thin-sections studied. Many of the larger feldspars are micropoikilitic, the inclosures consisting of quartz and feldspars.

Biotite is the third essential constituent; it is deep brown and strongly pleochroic. It is distributed through the rock in single long and stout shreds and as small aggregates. This constituent is subject to some variation, both in size of shred and in amount, the rock becoming, according to quantity, either lighter or darker in color. Under the microscope, numerous inclusions of the older minerals are seen in the biotite, among the most important of which are zircon, apatite, and magnetite. In a majority of the thin-sections a little primary muscovite is intimately associated with the biotite, occasionally as parallel growths, and, at times, the two micas penetrate each other, always preserving sharp and clear-cut boundaries. Much chlorite occurs as an alteration product of the biotite. Epidote, while not abundant, is usually present in many of the sections, always as an alteration product from the interaction of the biotite and feldspars, and is associated with the biotite.

Titanite is present to a limited extent in many of the sections, mostly as irregular grains and aggregates, but sometimes as wedge-shaped crys-

tals. The color varies from nearly colorless to reddish brown, with noticeable pleochroism in the deeper colored ones.

The other accessories present no special interest from their usual occurrence in granites.

Pressure metamorphic effects are clearly defined in all the thin-sections of this type of granite. They are more strongly marked in the granite from the Petersburg part of the area than that from the Richmond portion. As seen under the microscope, the pressure effects are shown in an optical disturbance of the quartzes and feldspars, more marked in the former, in the form of a wavy or undulous extinction; in a fracturing of the quartz and feldspar, which is quite strongly developed in some of the plagioclase individuals of thin-sections from the Petersburg area; and, lastly, in peripheral shattering or granulation of the larger quartz and feldspar individuals in the granite from the Petersburg area; also, in several instances biotite shreds were noticed broken across, and in still other cases the folia were markedly curved or bent.

At the Netherwood quarry, several miles west of Richmond, this type of granite is typically shown, and in some of the largest quarried blocks dressed up during the sumer of 1905 a distinct schistosity was discernible. As a rule, however, the rock from this quarry and from the Richmond area in general belonging to this type appears massive. In the Petersburg part of the area the dynamic effects are the most pronounced in thin-sections of this type of granite and a tendency toward a rough parallel arrangement of the minerals or schistosity is shown on close examination of the rock in nearly every opening.

The Richmond-Fredericksburg dark blue granite.—This type does not differ essentially in mineralogy from the light gray type described above, although the two bear no resemblance to each other in hand specimens. The dark blue is much more finely crystalline, the anhedra averaging less than 0.5 millimeter. The biotite is very uniformly distributed through the rock in minute irregular shreds which impart the pronounced dark blue color to the granite. Like the light gray type, this is a biotite granite containing a very little muscovite associated with the biotite. Plagioclase and microcline, in quantity and occurrence, characterize equally the dark blue type as the light gray.

Microscopically the two types are unlike in the degree of pressure effects indicated. The dark blue granite is entirely massive, and the only effects of pressure metamorphism discernible in the thin-sections is that of undulous extinction of, and occasional fractures in, the quartz. In the Fredericksburg portion of the area the rock is a shade darker in color than most of the same type in the Richmond area. The texture is the

same from the two areas, but in those quarries opened in the vicinity of Richmond, there is perceptible variation in the degree of color.

The Fredericksburg light gray granite.—This type occurs about one mile west of Fredericksburg, on Hazel run, and consists of anhedra averaging about 2 millimeters. It is essentially a muscovite granite, containing quite a sprinkle of closely associated biotite with the muscovite. It somewhat resembles the Stone Mountain light gray biotite-bearing muscovite granite of Georgia. An occasional crystal of red garnet is observed in the rock.

The effects of dynamic metamorphism are manifested in the rock in a thinly foliated structure which is only discernible on close examination. Thin-sections show quartz, orthoclase, microcline, plagioclase, muscovite, biotite, apatite, rutile, and zircon. The principal secondary minerals are chlorite and muscovite. Muscovite is partly primary and partly secondary. Microcline and plagioclase are in large amount. Intergrowths of the feldspars, and of the feldspars with quartz, are quite frequent. Micropoikilitic structure in the larger feldspars is strongly indicated. Partial orientation of the mica along parallel directions; an occasional bent and broken muscovite shred; fractured quartzes with wavy extinction, and the perfect granulations of the quartz feldspar individuals and the interstices filled in with the fine mozaic of the two minerals are pressure effects plainly marked in the thin-sections.

The Falls Church types.—The granites in the vicinity of Falls Church, Fairfax county, are of two varieties. One is a medium to finely crystalline rock and contains dominant biotite with some muscovite as the third essential component. The ratio of muscovite to biotite is variable, and while muscovite may be considerable in a few instances, the granites of this area contain dominant biotite. The other, a light and dark speckled rock, is a fraction more coarsely crystalline and is a hornblende-biotite granite. It is the only representative of a hornblende granite* yet found in the state and it is somewhat closely allied with quartz-diorite. It is closely associated in the field with diorite masses on the one hand and with foliated mica-granites on the other. The associated diorites are partly altered to metadiorites.

Petrographically it more properly belongs with the grano-diorites, differing from the diorites proper in increased quartz and potash feldspar. Thin-sections show quartz, plagioclase, orthoclase, green and brown hornblende, biotite, apatite, rutile, and the secondary minerals epidote, sericite,

* Hornblende syenite occurs at several localities in the state, but no recognition is taken of this rock in this paper. The boundaries of the syenite areas are unknown at present, but it is possible that future study will reveal increased quartz in sufficient quantity to differentiate a part of the rock of these areas as a hornblende granite.

garnet, chlorite, and kaolin. Hornblende is one of the most abundant constituents and at times it completely incloses shreds of the biotite. Microcline does not occur. Plagioclase is probably slightly more abundant than orthoclase. Metamorphic effects are indicated in the optical disturbance of the quartz and feldspar; in fractures crossing the quartz; in curved and bent lamellæ of a part of the plagioclase, and in the marked distortion of the cleavage angle of the hornblende.

The Annandale type.—This type is a medium gray and medium textured massive biotite-granite, intermediate in texture and color between the Richmond light gray and dark blue types. It is mineralogically similar to the Richmond types. Orthoclase is the dominant feldspar. Considerable microcline is present, but plagioclase is less abundant than elsewhere. Quite a sprinkle of idiomorphic sections of garnet is noted. Crushing effects are somewhat strongly marked in the thin-sections in the partial granulation of the quartz and feldspar, with the fine mosaic of the two minerals filling the interspaces of the unmashed portions of these minerals.

Unakite.—This type of rock derives its name from the Unaka mountains in western North Carolina and eastern Tennessee, where the rock was first observed and described.* Until very recently, knowledge of it was limited to a single locality in Virginia, namely, at Milams gap, in the Blue ridge, near Luray, but it has been noted near Troutdale, in Grayson county.† The mineral composition of the rock from the Virginia and North Carolina-Tennessee localities places it among the granites, with epidote as an essential constituent, but, according to an analysis by Phalen‡ of specimens from Milams gap, the rock is relatively basic for a granite.

The rock is a moderately coarse but irregular crystallization of red feldspar, quartz, and green epidote. Irregular crystallization of the rock is shown in the variation of masses composed of more than two-thirds of the red feldspar through all gradations to masses composed of quartz and epidote without feldspar, epidosite (see Phalen, page 312). Thin-sections of the unakite from Milams gap show epidote, orthoclase, quartz, iron oxide, zircon, and apatite. The epidote is secondary,§ replacing pyroxene and feldspar, both plagioclase and orthoclase.

The unakite-bearing rock at Milams gap is, according to Phalen, a hypersthene akerite (hypersthene-quartz-diallage-syenite), a coarse grained dark grayish green aggregate of essentially feldspars and black pyroxenes.

* F. H. Bradley: Am. Jour. Sci., 3d series, vol. cvii, 1874, pp. 519–520.
† Thomas L. Watson: Am. Jour. Sci., vol. xxii, 1906, p. 248.
‡ W. C. Phalen: Smithsonian Miscellaneous Collections, vol. xlv, 1904, pp. 306–316.
§ W. C. Phalen: Op. cit.

Thin-sections of the syenite reveal the following minerals: Orthoclase, plagioclase, orthorhombic and monoclinic pyroxene, quartz, microcline, iron ore, apatite, and zircon, with the alteration products epidote, chlorite, and sericite. Hornblende is essentially absent in the thin-sections. Phalen regards the unakite as having originated from the akerite by hydrometamorphism aided by dynamic disturbances.

The following analyses of the unakite and the unakite-bearing rock—akerite—are quoted from Phalen (page 313):

	Unakite, Milams gap. Phalen, analyst.	Hypersthene akerite Milams gap. Phalen, analyst.
SiO_2*	58.32	60.52
Al_2O_3	15.77	16.99
Fe_2O_3	6.56	.60
FeO	.89	6.53
MgO	.09	1.59
CaO	11.68	4.58
Na_2O	.32	2.83
K_2O	4.01	3.91
H_2O	1.73	.88
P_2O_5	.48	.74
MnO	.13	.25
Cr_2O_3	.....	trace
ZrO_2	trace	trace
	99.98	99.42

Porphyritic Granite

Unlike the crystalline region of North Carolina and Georgia, porphyritic granites are but scantily developed in the Virginia area. The best developed and most typical area in the state is that bounding the eastern margin of the Richmond coal basin near Midlothian, 13 miles west of Richmond and extending for a north-south distance of about 20 miles. This marks the western limits of the even-granular granite quarried around Richmond and Petersburg. Both are biotite granites and only differ from each other texturally.

The rock in the vicinity of Midlothian is a coarse porphyritic biotite granite, the porphyritically developed mineral of which is potash feldspar. The phenocrysts are of large size, 2 or more inches; idiomorphic in outline and contain biotite inclusions; often twinned on the Carlsbad law, and are in part orientated in a general northeast-southwest direction from flowage of the rock. The porphyritic texture, with variations, is traced as far north as Gayton, in Henrico county, and as far south as

* Including TiO_2.

Winterpock, in Chesterfield county. The evidence seems quite clear that the porphyritic granite underlies in part the eastern portion of the Richmond coal basin, but its relations to the crystalline rocks on the west can not be stated, since the line of contact is concealed beneath the cover of Newark rocks of the coal basin.

Granite-gneisses

Gneisses of granitic composition make up one of the principal rock types in the Virginia Piedmont complex. Many of these gneisses were derived from original massive granites, and they are invariably of the mica type. In mineral composition the granite-gneisses are essentially identical with the massive granites, except that hornblende is associated with biotite in the Richmond and Fredericksburg areas. In some of the slides hornblende is largely in excess of the biotite.

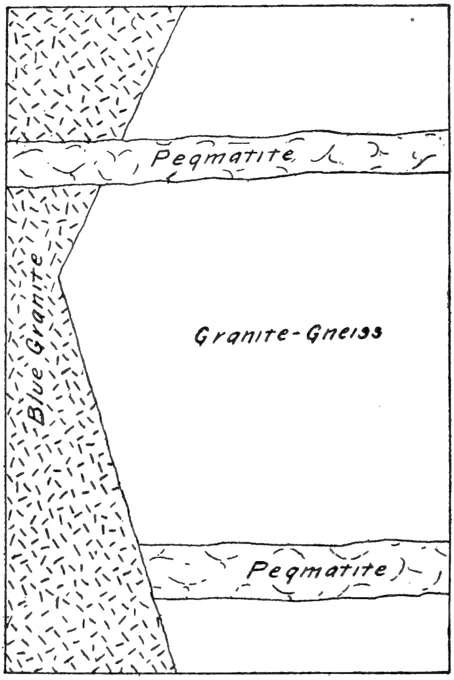


Figure 1.—*Contact of Hornblende-biotite Gneiss with Granite.*

At McGowan quarry south of Richmond. Granite cuts directly across schistosity of the gneiss; the pegmatites conform with the schistosity.

The gneisses differ from the granites principally in the banded structure induced in the former through the action of pressure metamorphism. The banding may be fairly regular, but, as a rule, it is quite irregular; in either case the bands are composed of alternating ones of light and dark colored minerals. The individual bands may vary much in thickness.

Between the entirely massive granite and the typical granite-gneiss intermediate grades of schistosity are easy of differentiation over parts of the Virginia area. This undoubtedly means that in some of the areas a less schistose granite may grade into a more schistose one. In other areas this interpretation is not possible, for the massive granites are sharply defined structurally from the schistose ones, and in all cases where contacts were found it was entirely clear that the

massive rock was younger and had been intruded into the schistose rock. The evidence for this is discussed elsewhere in this paper.

The Richmond-Fredericksburg Gneiss

This is the oldest of the acid rocks in the Richmond-Fredericksburg areas and it is invaded by both the light gray and dark blue massive granite. Figure 1 shows the relations between the dark blue granite and the gneiss at the McGowan quarry, south of Richmond. Similar relations obtain in the quarries 3 miles north of Fredericksburg. The period of deformation inducing the schistose structure in the gneiss antedates that of the intrusion of the massive granite, as evidenced by the massive granites cutting across the schistosity of the gneiss and by inclusions of the gneiss in the granites which preserve perfectly the gneissic structure.

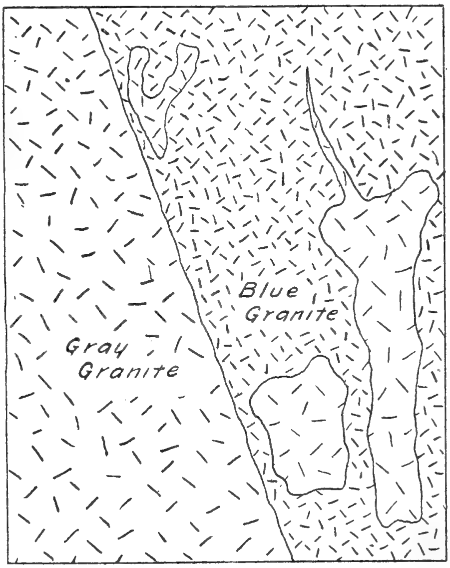


Figure 2.—*Contacts between the Gray and Blue Granites.*

Locality Netherwood quarry. Inclusions of the older gray granite are shown in the blue granite. Scale, 1″ = 9″.

The rock is a hornblende-biotite gneiss of medium texture and irregularly banded. The principal minerals are quartz, orthoclase, plagioclase, hornblende, biotite, sphene, and apatite. Chlorite occurs as an alteration from biotite. The principal features to be noted in the composition of the gneiss are: (1) The presence of essential hornblende, which greatly exceeds biotite in amount in some of the sections; (2) the absence of microcline—a mineral always present in the massive granites; and (3) the presence of much plagioclase, which is the dominant feldspar in a few sections and nearly or quite equals orthoclase in amount in others.

Structural Relations of the Granites in the Richmond-Fredericksburg Areas

TYPES

Three types of rocks of granitic composition are represented in the Richmond area; two are massive granites; the third is a schistose granite

or granite-gneiss. The two massive granites are designated above as the light gray granite and the dark blue granite. Three periods of intrusions are accordingly represented in the following order, beginning with the earliest: (1) The granite-gneiss, (2) the Richmond-Petersburg light gray granite, and (3) the Richmond-Fredericksburg dark blue granite. This succession is plainly indicated in the field and is further confirmed by microscopic evidence.

CONTACTS

The numerous quarries worked in the vicinity of Richmond afford excellent opportunity for studying the contacts between the fresh granites of the three types named above. As noted in the description detailed above of the three types, the difference in color, texture, and structure render them easy of differentiation. From the large number of contacts examined not one has shown the presence of contact minerals. Several

FIGURE 3.—*Relations of the Blue to the Gray Granite.*

As shown at the Netherwood quarry west of Richmond. Scale, 1″ = 159′.

of the contacts show inclosures of the older granite in the newer one. At one of the contacts between the light gray and the dark blue granites in the Netherwood quarry the younger or dark blue granite contains numerous irregular and varying size fragments of the light gray granite, as shown in figure 2. Again, other exposures in the same quarry reveal the true relations of the two granite types. As shown in figure 3, the dark blue granite invades the gray granite in two separate, nearly vertical dike-like arms. Figure 2, plate 69, is from a photograph of one of the arms of the dark blue granite showing jointing of the rock. The same relation of these two types is equally well shown in the dark blue granite penetrating the light gray granite in the Philadelphia quarries at the head of the settling basin near Richmond.

FIGURE 1.—McGOWAN GRANITE QUARRY, SOUTH OF RICHMOND, VIRGINIA

Showing sheeting from horizontal jointing approximately parallel to the surface

FIGURE 2.—VERTICAL AND HORIZONTAL JOINTING, NETHERWOOD GRANITE QUARRY, WEST OF RICHMOND

GRANITE QUARRIES IN VIRGINIA

At the McGowan quarry, several miles south of Richmond, and the Cartright and Davis quarries, 3 miles north of Fredericksburg, contacts between the granite-gneiss and the dark blue granite are beautifully shown. At both places the granite cuts directly across the schistosity of the gneiss, as shown in figure 1. Plate 72, figure 2, is from a photograph of an inclusion of the gneiss in the blue granite. It is entirely clear that the period of intrusion of dark blue granite was subsequent to the period of deformation producing the schistose structure of the granite-gneiss.

APOPHYSES

At the Cartright and Davis quarries, 3 miles north of Fredericksburg, the sloping floor of the granite-gneiss in one of the openings contains numerous large and small dikes or tongues of the dark blue granite penetrating the gneiss. These have the same texture, color, and composition as the parent mass and they conform in part with the schistosity of the inclosing gneiss and in part cut directly across it. Similar conditions obtain at the McGowan quarry, several miles south of Richmond. The Fredericksburg quarries furnish the best illustration of granite tongues penetrating from the parent mass into the inclosing rock.

INCLUSIONS

The inclusions are of two kinds: First, those which correspond in composition and otherwise with the inclosing rock and plainly represent fragments of the country rock torn off during the intrusion of the granite containing them. In the Richmond-Fredericksburg areas the dark blue granite in some of the quarries contains inclusions of the massive light gray granite (figure 2) and of the gneiss (plate 72, figure 2). The foliation of the gneiss is entirely preserved in the inclusions of the rock. No appreciable metamorphism was observable in the contacts of the country rock and the inclusions.

The second type of inclusion is a massive basic segregation from the magma. It consists of dominant biotite, a little feldspar and quartz, and of variable sizes and shapes. Where observed, a tendency toward an elliptical or much elongated mass is shown. The composition of these bodies entirely comports with that of the inclosing rock, granite, except that biotite is very largely in excess. These basic inclusions are abundantly developed in the hornblende-biotite granite of the Falls Church area, where they assume very large dimensions in many cases. The Richmond,

Petersburg, and Fredericksburg granites show comparative freedom from them, and usually they are of very small dimensions.

The Aplites and the Pegmatites

The aplites are only occasionally met with in the Virginia granite areas. They have been noted by the writer only in the Richmond granite area. A banded aplite-pegmatite of small dimensions, shown in figure 4, penetrates the dark blue granite of the McGowan quarry south of Richmond. In the vicinity of Midlothian, 13 miles west of Richmond, the porphyritic biotite granite is cut by a number of small aplite dikes. Where these have been observed they are plainly of an intrusive nature, cutting the granite proper and not the inclosing gneisses.

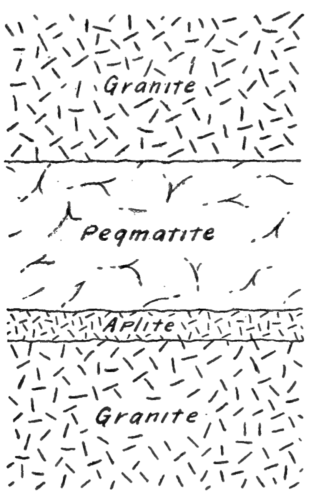


FIGURE 4.—*Banded Aplite-Pegmatite Intersecting the Blue Granite.*

McGowan quarry, south of Richmond. Scale, 1″ = 5″.

Pegmatites are abundantly developed in the Richmond-Fredericksburg areas and at times are of large size. Only in one or two instances do they seriously interfere with quarrying operations. They are of granitic mineralogy, without the occurrence of unusual or rare minerals noted in them, and they cut alike the granites and the gneisses.

They consist of coarse aggregates of feldspar and quartz, with more or less black biotite and a little muscovite. In the Fredericksburg quarries of dark blue granite, where the pegmatites are particularly abundant, massive granular magnetite and large and small perfect red crystals of garnet are not infrequent constituents. The dodecahedron and trapezohedron are the commonest forms of the garnet. The feldspar exhibits a variety of colors, from white opaque and pink to a decided medium green, the former two being the commonest shades. Thin-sections show both orthoclase and microcline under the microscope. An acid plagioclase is present in some of these veins. The numerous quarries in the Richmond area afford excellent opportunity for studying the pegmatites and some interesting data have been obtained bearing on their comparative age relations.

It has been shown above that there are three granites, including the granite-gneiss in this area, representing as many periods of intrusion. The order of these intrusions, beginning with the oldest, has been shown

Figure 1.—Netherwood granite Quarry, west of Richmond, Virginia

Showing vertical, diagonal, and horizontal jointing

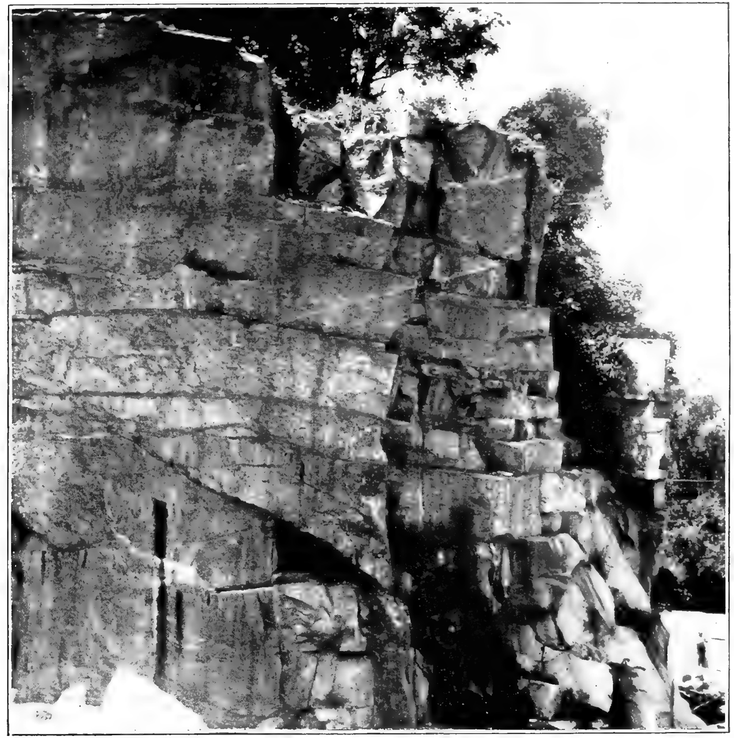


Figure 2.—Wray granite Quarry, west of Richmond, Virginia

Showing diagonal and horizontal jointing

GRANITE QUARRIES IN VIRGINIA

to be: (1) Granite-gneiss, (2) Richmond-Petersburg light gray granite, and (3) the Richmond-Fredericksburg dark blue granite. As shown in the accompanying figures, sketched from quarry openings in the field, the granite mass of each intrusion was accompanied by the formation of pegmatitic material. Some of the pegmatites intersecting the dark blue granite which represents the latest of the granite intrusions also penetrate the light granite, and in some cases the earliest of the intrusions, granite-gneiss. These conditions are well illustrated in figures 1 and 5, which show that the latest formed pegmatites intersecting the dark blue granite also extend into and intersect respectively the granite-gneiss and

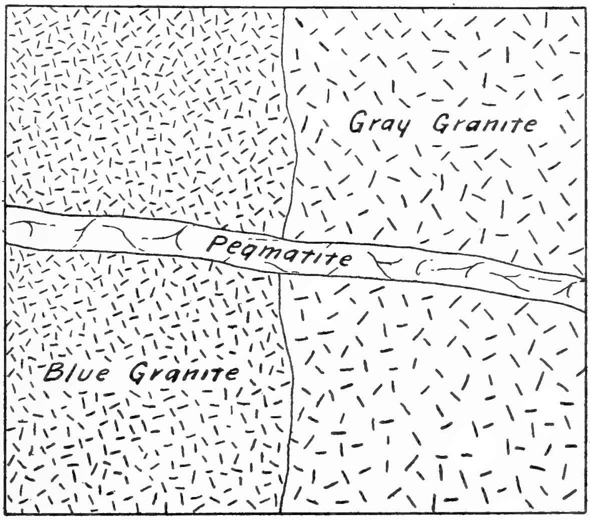


FIGURE 5.—*Contact between Blue and Gray Granite.*

Netherwood quarry, west of Richmond. The same pegmatite cutting both granites is shown.

the light gray granite; also figure 1 shows that a pegmatite which characterized the earliest period of intrusion, granite-gneiss, is abruptly cut off by the intrusion of the dark blue granite into the granite-gneiss. It will be observed from the figure that where the pegmatite is cut off by the dark blue granite it is equally as wide as in any other portion of the dike, traced for some distance in the exposed granite-gneiss. Moreover, those pegmatites which belong to the latest period of intrusion and which intersect the dark blue granite are found intersecting each other in such manner as to indicate earlier and later formation. Figure 6, which shows this, also shows that the oldest or intersected pegmatite is faulted

along the youngest or intersecting pegmatite. There is no evidence for regarding this relation of the pegmatites as due to branching, but the facts all support faulting as the cause.

Those pegmatites which intersect the granite-gneiss in some cases follow the schistosity, as in figure 1, and in other cases they cut across the schistosity, as in figure 7. Plate 71, figures 1 and 2, are from photo-

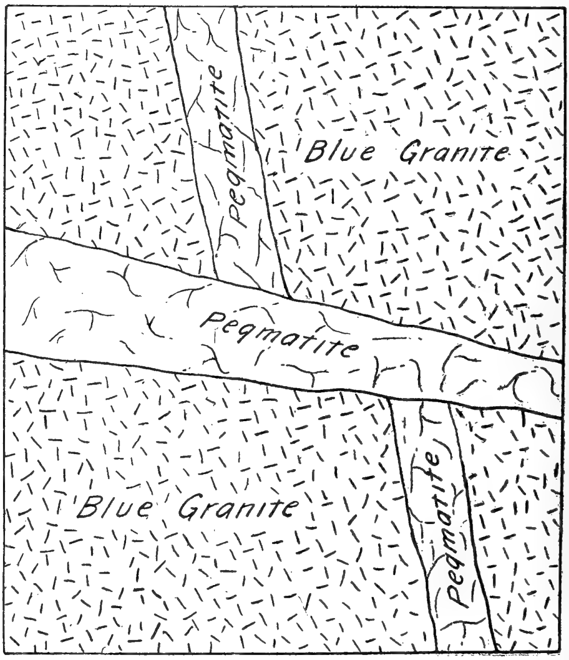


FIGURE 6.—*Faulted Pegmatite intersecting Blue Granite.*

The Donald quarry, west of Richmond.

graphs of pegmatites cutting the dark blue granite in the quarries at Fredericksburg and Richmond.

Where observed, the pegmatites are sharply defined from the inclosing rock; parallel banding to the walls does not occur; their composition is essentially similar to that of the inclosing granite, and all of them are entirely massive, without any evidence of pressure metamorphism shown in them. This last feature, massive character, has an important bearing on the question of the relative periods of formation of the pegmatites and that of the granite-gneiss which they intersect. In case the gneiss represents an original massive granite, which seems reasonably sure, it

FIGURE 1.—PEGMATITE DIKE

Cutting blue granite in Davis quarries, 3 miles north of Fredericksburg, Virginia

FIGURE 2.—PEGMATITE VEINS CUTTING GRANITE, DONALD QUARRY, WEST OF RICHMOND

PEGMATITE DIKES AND VEINS

must follow that the massive pegmatites which characterize it must have formed after the period of deformation which induced the banded or schistose structure in the gneiss. Again, this series of pegmatites must have formed prior to the periods of intrusion of the light gray and the dark blue granites, as shown in figure 1.

Joint Systems

GENERAL CHARACTER

The Virginia granites are intersected by three systems of joints—a vertical set, a diagonal set, and a horizontal set. These may be widely spaced or closely spaced. Usually the spacing is sufficiently wide to admit of dimension stone being quarried. The vertical set of joints is usually more strongly developed than the diagonal, and in some of the granite-masses both sets occur.

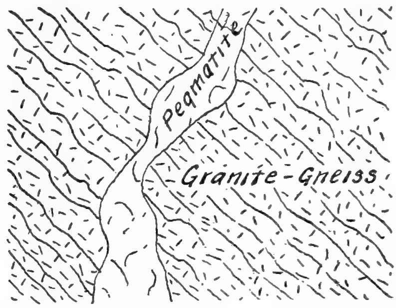


FIGURE 7.—*Pegmatite cutting across the Schistosity of the Granite-gneiss.*

Middendorf quarry, west of Manchester.

Measurements of the strike of the joint-planes made in the quarries can be summarized as follows: Two sets of joints whose planes lie in the northeast and northwest quadrants respectively and compose the major jointing, and two minor sets striking east-west and north-south. Strike of the joint-planes in the northeast and northwest quadrants shows the limits of variation to be north 5° east or west to north 80° east or west. Only a few of the planes strike east-west and north-south.

The inclined joints are less abundant than the vertical ones, and they dip at angles varying from 20 to 82 degrees. The dips are toward the northeast, east, and southeast, northwest and southwest. On plate 69, figure 2, and plate 70, figures 1 and 2, are shown the two systems of vertical and inclined joints. Some movement in the granite masses since the formation of the joints is indicated in the development of slickensides on the joint surfaces. Polished and striated surfaces are fairly abundant.

HORIZONTAL JOINTS

Joints which approximate horizontality in position are strongly developed in the granites of Virginia and of the southern States in general. Careful observation over the southern region by the writer has developed two characteristics of this set of joints:

(1) The visible joints that lie entirely or approximately in the horizontal plane are a surface feature, becoming less emphasized with depth and are not observed in the lower portion of the rock in some of the deeper quarries. As a rule, the planes separate the rock into thinner sheets at or near the surface and into thicker sheets on depth.

(2) The joints of this set are developed parallel to the granite surface. In the flat surface exposures of granite this set of joints lie entirely in the horizontal plane. In the gently arched exposures the joints observe approximately the same degree of curvature as that of the granite surface, and in the steep domes the joints are correspondingly steep, observing parallelism with the doming surface.

In the opinion of the writer, the above facts indicate weathering as the cause of this set of joints; exfoliation to be largely attributed to temperature changes.* Curved joints undoubtedly exist in some granite masses below the exfoliating surface and, as Merrill says, are "the result of torsional strains and once existing are lines of weakness which become more and more pronounced as weathering progresses."†

Doming granite masses do not occur in the Virginia area and the joints belonging to the above class are practically horizontal. Plates 69, 70, and 72, reproduced from photographs taken in the Virginia quarries, show a strong development of horizontal jointing.

* G. P. Merrill: Rocks, rock weathering and soils, 1897, pp. 180–184.
† Ibid., p. 245.

FIGURE 1.—COOK'S GRANITE QUARRY, NORTH OF PETERSBURG, VIRGINIA
Showing horizontal jointing parallel to surface

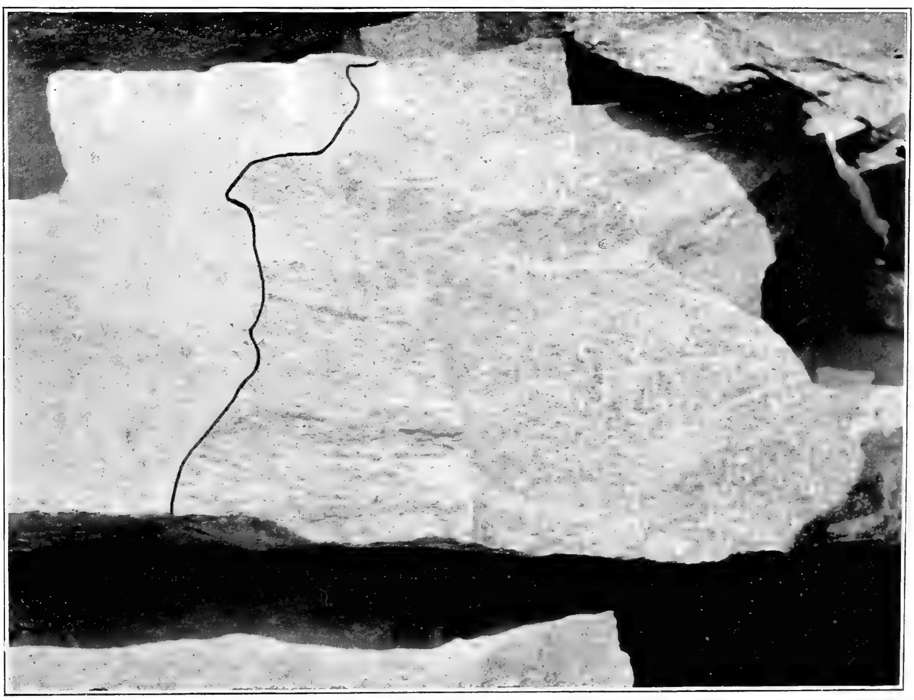
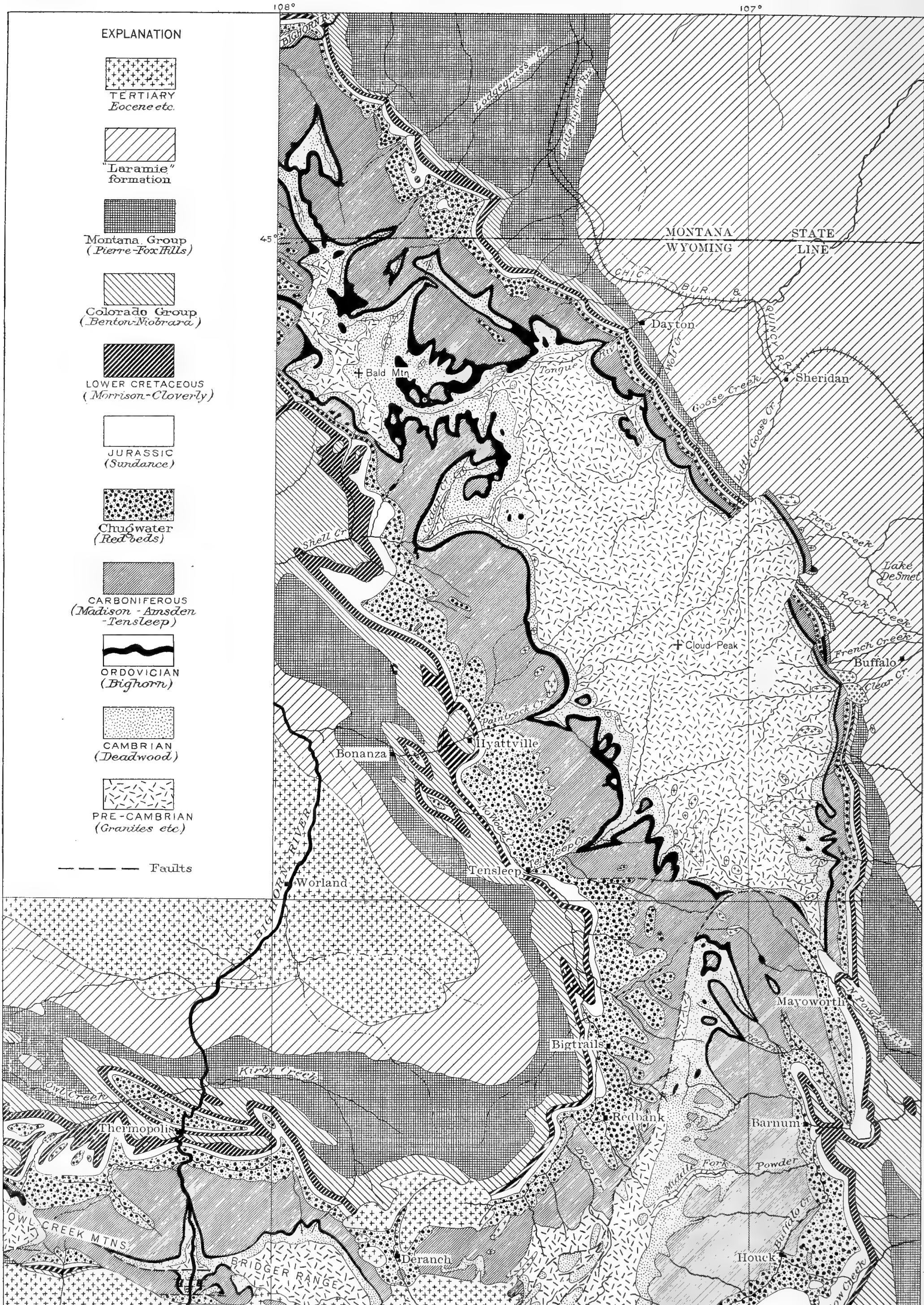


FIGURE 2.—INCLUSION OF GNEISS IN BLUE GRANITE AT MCGOWAN QUARRY, SOUTH OF RICHMOND

GRANITE QUARRY AND GNEISS INCLUSION



GEOLOGIC MAP OF BIGHORN MOUNTAIN

By N. H. Darton.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 17, PP. 541-566, PLS. 73-79   DECEMBER 31, 1906

FISH REMAINS IN ORDOVICIAN ROCKS IN BIGHORN MOUNTAINS, WYOMING, WITH A RÉSUMÉ OF ORDOVICIAN GEOLOGY OF THE NORTHWEST

BY N. H. DARTON*

(Presented in abstract before the Society December 29, 1905)

CONTENTS

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Introduction

The purpose of this paper is to announce the discovery of fish remains in rocks of Ordovician age in the Bighorn mountains and to describe the character and relations of the rocks in which they occur. There will be added a few statements regarding the similar occurrence of fossil fish in the Ordovician sandstone near Canyon City, Colorado, announced by Mr C. D. Walcott in 1892†, and a brief review of our knowledge of the Ordovician geology of the Northwest.

General Geology of the Bighorn Uplift

GEOGRAPHY

The Bighorn mountains are an outlying portion of the Rocky Mountain range, extending from north-central Wyoming into the south-central portion of Montana. They rise abruptly out of the Great plains, which have an altitude of 4,000 to 5,000 feet, to altitudes which range from 10,000 to slightly over 13,000 feet in the higher mountain summits. The portion of the range to which the term Bighorn mountains is applied trends north-northwest in the northern portion of its course and nearly due north and south in the southern portion, where it joins a high east-west range known as the Bridger range and Owl Creek mountains.

The Bighorn mountains end at the north at the canyon of Bighorn river, beyond which the same uplift is continued in the Pryor mountains, a range of moderate elevation, which extends but a short distance. West of the Bighorn mountains there is a wide area of plains known as the Bighorn basin, which extends to the foot of the Shoshone mountains on the west and the Bridger range and the Owl Creek mountains on the south.

STRUCTURE

The Bighorn mountains are due to a great anticline of many thousands of feet uplift, which has brought a thick series of Paleozoic and Mesozoic sedimentary rocks high above the adjoining Great plains. Owing to the deep erosion of the crest of this uplift, the mountains present a central nucleus of pre-Cambrian granites, with the sedimentary rocks on the flanks of the mountains and constituting plateaus at either end. The region is one of exceptionally fine exposures, which afford a rare opportunity for study of the stratigraphic relations and variations. Most of the rocks are hard, and streams flowing out of the central mountain area have cut deep canyons and gorges, in the walls of which the formations

† Bull. Geol. Soc. Am., vol. 3, pp. 153-172, pls. 3 and 5.

are often extensively exhibited. The structure presented locally is usually that of a monocline dipping toward the Plains on the east side and the Bighorn basin on the west. The oldest sedimentary rocks usually are at the base of a ridge facing the interior granite area, and each higher stratum passes beneath a newer one in regular succession outward toward the margin of the uplift. In figure 1 there is given a cross-section showing the general structure in the higher portion of the uplift.

In this section the anticline has steep sides, especially on the west, but in places the steeper dips are on the east side, and in some portions of the uplift they are gentle on both sides. In the northern portion of the area, where the strata cross the arch, the crest of the uplift is nearly flat.

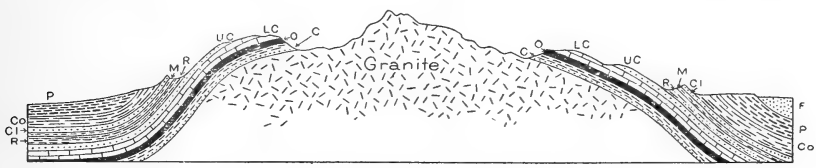

FIGURE 1.—*Typical Section across the Bighorn Mountains.*

Showing the general structure in the higher portion of the uplift. C, Deadwood formation (Middle Cambrian) ; O, Bighorn limestone ; LC, Madison limestone (Lower Carboniferous) ; UC, Amsden and Tensleep formations (Upper Carboniferous) ; R, Red beds ; M, Sundance (Jurassic) and Morrison ; Cl, Cloverly sandstone ; Co, Colorado group ; P, Pierre shale ; F, Parkman sandstone (Fox Hills ?).

Several great faults break the monoclinal slopes, and in the southern portion of the range a great dislocation extends for many miles along the higher portion of the mountain, parallel to the strike of the uplift and near its crest.

ROCKS

The sedimentary formations consist of a series of thick sheets of sandstone, limestone, and shales, all essentially conformable in structure, although lacking some members of the geologic succession. Quaternary deposits of glacial origin lie on the granites in the highlands, and fluviatile gravels and sands are on terraces overlapping the older sedimentary rocks on the Plains. The stratigraphy presents many features of similarity to the succession of rocks in the Rocky mountains of Colorado and Wyoming and the Black hills, but it possesses numerous distinctive local features. The following is a list of the formations which are exhibited in the uplift, with a generalized statement as to thickness, characteristics, and age. The broader features of distribution are shown in the map (plate 73).

Generalized Section in the Bighorn Mountains

Formation.	Character and age.	Average thickness.	Age.
		Feet.	
Laramie? De Smet formation.	Gray sandstone and carbonaceous shales, with lignite deposits.	5,000+	Upper Cretaceous (and Eocene ?).
Laramie? Kingsbury conglomerate.	Local conglomerate of central-eastern district.	0–2,000	Upper Cretaceous (and Eocene ?).
Laramie? Piney formation...	Brown and gray sandstones and shales.	2,000–3,000	Upper Cretaceous (and Eocene ?).
Parkman (Fox Hills?) sandstone.	Soft, buff, massive sandstone with harder darker concretions.	300– 500	Upper Cretaceous.
Pierre shale...............	Dark gray shale with concretions.......	1,200–3,500	Upper Cretaceous.
Colorado formation....	Gray shales, thin brown sandstones below, hard fine gray sandstones (Mowry beds) in middle part, concretions with Prionocyclus, etcetera, at top.	1,250–1,500	Upper Cretaceous.
Cloverly formation.....	Buff, coarse massive sandstone below with light-colored shales and some sandstones above.	80– 200	Upper and Lower Cretaceous (Dakota-Fuson Lakota).
Morrison formation....	Massive shales, greenish-gray, buff, maroon, with thin sandstones.	150– 300	Lower Cretaceous ?
Sundance formation...	Soft sandstones overlain by greenish-gray shale ; several hard fossiliferous layers near top and bottom.	250– 450	Jurassic.
Chugwater formation.	Red shales and soft sandstone, thin limestone layers near top and bottom, and gypsum deposits.	700–1,300	Triassic ? and Permian.
Tensleep sandstone...	Massive buff to gray sandstone, calcareous near top.	30– 150	Carboniferous (Pennsylvanian).
Amsden formation.....	Red shales or sandstone at base, overlain by fine grained white limestone, cherty near top.	200– 350	Carboniferous (Pennsylvanian and Mississippian ?).
Madison limestone....	Light colored limestones, very massive near top.	700–1,100	Carboniferous (Mississippian).
Bighorn limestone......	Mostly hard massive limestones with streaks of silica, overlain by series of softer purer limestones with local shaly limestones, 0–30 feet of white sandstone at base.	250– 300	Ordovician (lower member Trenton), upper member Richmond).
Deadwood formation..	*Feet.* Slabby limestones with flat-pebble limestone conglomerates, sandy to southeast.. 200 Green shale with sandstone layers.................................. 300–600 Brown massive sandstones.... 0-400	900–1,150	Middle Cambrian.
Granite.......................	Gray and red of various kinds, penetrated by diabase and other dikes.	....	Archean or Algonkian.

Ordovician of the Bighorn Mountains

GENERAL RELATIONS

As indicated in the above table, the Ordovician representative in the Bighorn mountains has been designated the Bighorn limestone,* and

* Bull. Geol. Soc. Am., vol. 15, 1904, p. 395.

probably it is the most conspicuous sedimentary formation in these mountains, for its hard, massive limestone outcrops in long high escarpments surmounting the slopes of Deadwood rocks. To the north its thickness averages about 300 feet, including an upper series of about 100 feet of softer, thinner bedded limestone and a basal white sandstone, which have been included in the formation mainly on account of their Ordovician age. In the southern portion of the uplift the formation thins out and is absent, but it reappears in the northern and western portions of the Bridger range.*

The principal exposures of the Bighorn limestone are in the lines of cliffs which face inward on the higher slopes of the limestone front ridge of the mountains, and it caps some of the highest divides in the Bald Mountain region. It is also a prominent feature in the numerous deep canyons leading out of the mountains, especially along Bighorn, Tongue, and Little Bighorn rivers and Shell, Lodge Grass, Wolf, Goose, Rapid, Paintrock, Tensleep, Canyon, Otter, Beartrap, and Crazy Woman creeks. Along either side of the higher part of the uplift the outcrop of the formation usually is narrow, but in the Bald Mountain region, where the strata lie more nearly level, some wider areas are exhibited. It caps the main divide north of Bald mountain and occurs on either side of the upper portion of Tongue River valley. In the high plateau between Tongue river and Shell creek it is largely covered by Madison limestone. In Hunt mountain the formation presents to the west a high, straight escarpment, which is visible from far out in the Bighorn basin. The formation is cut out for short distances by the great faults at various points along the uplift, so that it does not reach the surface. Its outcrop area is shown in plate 73.

CHARACTER

The massive limestone which constitutes the greater part of the formation is a rock usually of light buff color, somewhat darker when weathered, filled with a coarse mat or network of irregular, silicious masses, mostly from one-half to 1 inch in diameter. On weathering this silicious material stands out a half-inch or more on the rock surface as a ragged network, the purer rock between having been dissolved. The nature of this weathered surface is shown in figure 1, plate 76. This feature and the very massive bedding are characteristic. It is owning to the softness of the underlying Deadwood shales and the hard, massive nature of the Bighorn limestone that the latter forms high cliffs with a talus of huge blocks

* The first notice of Ordovician in the Bighorn mountains was in a paper by C. E. Beecher, Am. Geologist, vol. xviii, 1896, p. 32.

of the limestone on the slopes below. In plate 74 are shown some prominent outcrops of this member. In the canyons there are close, high walls where the streams cross the formation, and a vertical cliff as the rock rises in the slopes.

The upper portion of the formation consists of limestones softer and purer than those below, the bedding is thinner, color white to gray, and parts of the rock are very compact or fine grained, often resembling lithographic stone. There is considerable variation in the local features of this member, and its thickness varies from 75 to over 100 feet. In its basal beds corals occur, often in great abundance, especially along the central side of the uplift. In the greater part of the area there is included, a short distance above the coralline beds, a layer of hard, massive limestone with network of silica, similar to the great lower member of the formation, but less marked in character and only from 15 to 25 feet thick. Some shale and sandy limestone beds are also included. On the south branch of Rock creek the upper member of the formation is an impure, thin bedded, gray limestone which weathers to a reddish clay and contains large numbers of fossils of the Richmond fauna.

The basal sandstone of the formation is a distinct member separating the massive Bighorn limestone from the limestones and shales of the Deadwood formation. It is most extensively developed in the northern central portion of the uplift, where its thickness usually is from 25 to 30 feet. The rock is a moderately coarse grained, massive sandstone, mostly of light gray color. It thins to the northwestward and is absent at some localities in the vicinity of Shell creek and Little Bighorn river. It also thins south of latitude 44 degrees and finally ends with the termination of the Bighorn limestone a short distance north of Cheevers, a ranch 10 miles southeast of Bigtrails, excepting a small area on the West fork of Powder river, 12 miles farther southeast, where it has a thickness of 4 feet.

THICKNESS

North of Powder river the Bighorn limestone rarely varies materially from 300 feet in thickness, but in some localities the amount is slightly greater, notably in the lower part of Shell Creek canyon, where there are two beds of massive silicious limestone in the upper series. In Beartrap canyon (due west of Mayoworth) and the ridges southwest the formation shows rapid decrease in thickness, and finally it thins out southeast of Bigtrails, where the Madison limestone lies directly on the eroded surface of the Deadwood formation. In an outlying knob 8 miles southeast of Bigtrails the limestone is 25 feet thick and separated from the Deadwood

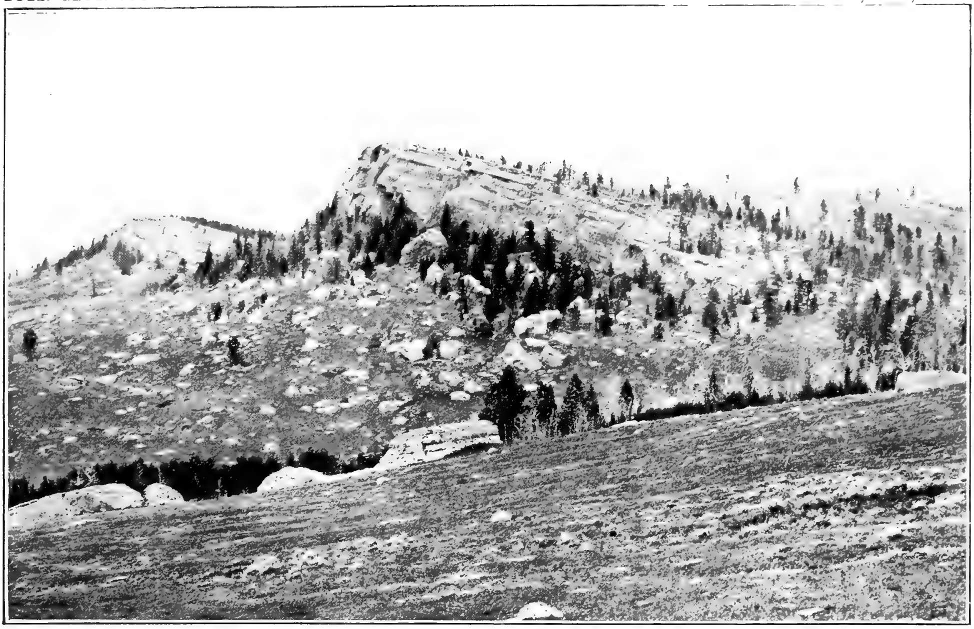

FIGURE 1.—TYPICAL CLIFFS OF MASSIVE BEDS OF BIGHORN LIMESTONE

On east slope of Bighorn mountains, west of Buffalo, Wyoming. Deadwood shales under talus in slopes to left; Madison limestone in ridges to right

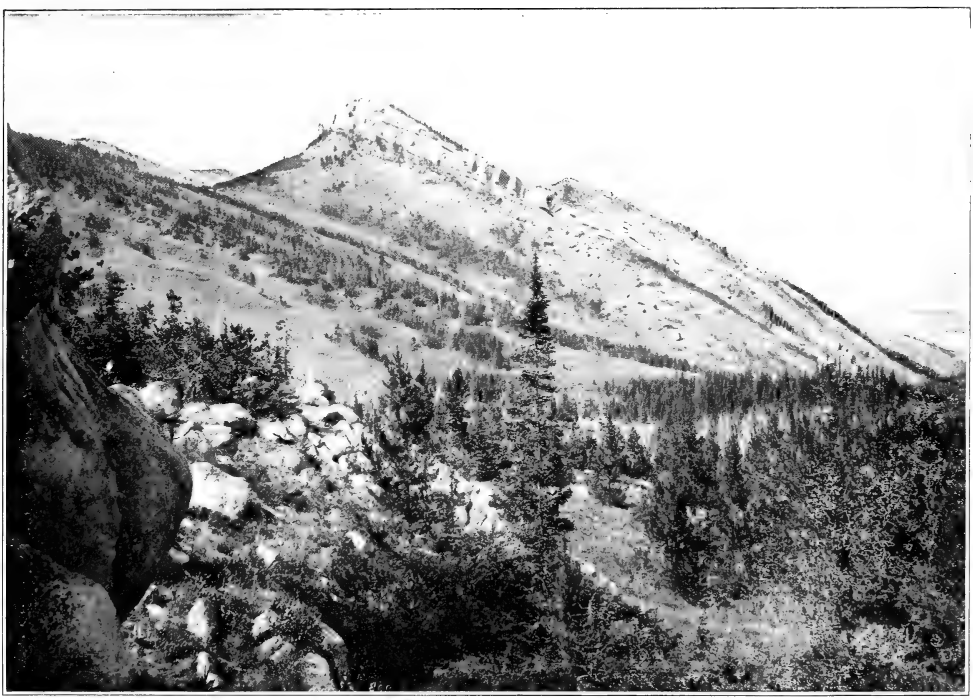

FIGURE 2.—RIDGE OF BIGHORN LIMESTONE

On east slope of Bighorn mountains, west of Sheridan, Wyoming. Slopes of Deadwood beds to left; granite on extreme left; Madison limestone to the right

EXPOSURES OF BIGHORN LIMESTONE

beds by a few feet of white quartzitic sandstone, the basal member of the formation. The characteristic massive limestone, with silicious network, reappears in the Bridger range west of Deranch, at first thin, but gradually thickening to 40 feet on branches of Buffalo creek southeast of Thermopolis, and to 50 feet or more in the upper canyon of Bighorn river.

STRATIGRAPHIC RELATIONS

The Bighorn formation lies unconformably between Middle Cambrian and earlier Carboniferous beds and includes near its upper part an unconformity representing a long period of later Ordovician time. These unconformities present no perceptible discordances in dips. The basal contacts, especially at the base of the white sandstone, are well exposed, but show mainly only a sharp change in materials. In a few cases there are slight local irregularities apparently due to channeling. The subjacent beds are Deadwood (Cambrian) limestones, but none of this material is discernible in the Bighorn sandstone. Where the sandstone is absent and the massive Bighorn limestone overlaps Deadwood limestone there appears not to have been local uplift and truncation of the sandstone, but simply a thinning out of the sandstone against the margin of a channel, or coastline, which is overlapped by the massive limestone. The contact between the massive limestone and the overlying thin bedded limestone (Richmond) unfortunately was not found sufficiently well exposed to afford information as to the precise relations. Judging from their distribution, the Richmond beds lie in shallow basins on an eroded surface of the massive limestone. The Bighorn-Madison contact is often exposed, but, although the hiatus represents all of Silurian and Devonian time, neither channeling nor fragmental products were observed, and usually it is not possible to discern the plane of contact. In a few places there appears to be a sudden change from one limestone to another, especially where the basal Madison beds are darker gray and slightly sandy.

The disappearance of the Bighorn formation to the southeast was examined with care, and, while there is some thinning of all the strata, the principal diminution of thickness clearly is due to erosion from the top down. Even in this part of the region neither discordance of dip nor channeling of the surface of the Bighorn limestone was perceptible, and there was no evidence of fragmental products in the overlying Madison limestone. It was seen, however, that at first the top bed of the massive Bighorn limestone was rapidly diminishing in thickness, and after it was gone the next thick stratum became thinner and thinner, and finally ended, so that Madison limestone came down onto Deadwood upper limestones, as shown in plate 75. The basal Bighorn sandstone *thinned*

out before the ending of the massive limestone. In the southward continuation of this increased unconformity it was found that finally in the vicinity of the heads of branches of Buffalo creek west of Houck the Deadwood limestones are eroded off and for a short distance the Madison limestone lies on the Deadwood shales. The supposed relations are shown in figure 2. Farther west in the Bridger range the Ordovician limestone comes in again, presenting relations similar to those in the Bighorn mountains, but without the basal sandstone so far as observed. Probably the Bighorn formation originally extended over the portion of this eroded area now included in the Bighorn Mountain uplift, and its present absence here is entirely due to erosion. The overlap apparently is due to locally increased uplift in post-Ordovician times at the north end of an anticline which involved the southeast corner of the Bighorn mountains

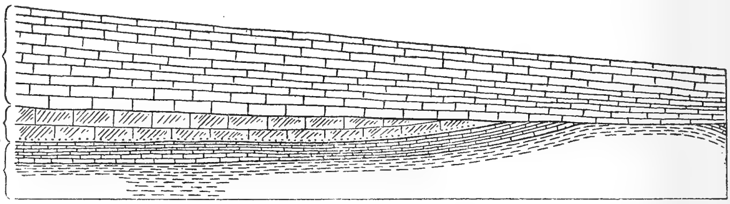

FIGURE 2.—*Ideal Section showing stratigraphic Relations in southern Part of Bighorn Mountains.*

and probably extended from the Laramie range. The original position of the shoreline of the Bighorn limestone to the south is not known.

INVERTEBRATE FOSSILS

The greater part of the Bighorn limestone yields but few fossils. Fragments of maclurinas and corals appear occasionally in the lower massive beds, and, as above staed, some beds of limestone near the base of the upper series contain corals in most localities. The principal species is a variety of *Halysites catenulatus* (*gracilis*), or chain coral, which often occurs in large numbers. The locality at which fossils were observed to be most abundant in the lower limestone member is on the top of Medicine mountain, a high peak 5 miles northwest of Bald mountain, in beds about 100 feet above the base of the formation. The following forms from this place were determined by Mr E. O. Ulrich: *Streptelasma* sp. undet., *Protarea* n. sp. (massive), *Plectorthis plicatella ?*, *Dinorthis pectinella ?*, *D. subquadrata ?*, *Rhynchotrema capax ?* var., *Oxydiscus* sp. undet., *Liospira*, sp. undet., *Trochonema* sp. undet. (near *T. robbinsi*), *Holopea excelsa ?*, and *Huronia* sp. undet., a lower Galena-Trenton fauna, as nearly as can be ascertained.

EXPOSURE OF MADISON LIMESTONE ON DEADWOOD FLAGGY LIMESTONE

On Deep creek, 7 miles southeast of No Wood, Wyoming, in southwestern portion of Bighorn mountains
The man's hand is on the contact

From the upper beds of the formation, at a point about 5 miles east of Bald mountain, the following fossils were collected: *Streptelasma* n. sp. (with trilobate calyx), *Calapœcia* sp. undet., *Favosites* sp. undet., *Stromatocerium ?* n. sp., *Dalmanella testudinaria* var., *Leptæna unicostata,* and *Rhynchotrema capax.* These were determined by Mr E. O. Ulrich, who regards them as of Richmond age.

Near the divide at the head of Cedar creek the upper member of the formation was found to be about 160 feet thick, and in the upper beds of this member the following forms were found: *Leptæna unicostata, Strophomena fluctuosa, Dinorthis subquadrata* (coarsely striated form), *Rhynchotrema capax.* In the middle beds are *Halysites gracilis* (abundant), *Streptelasma* sp. undet., *Diplotrypa westoni, Dalmanella testudinaria* var. (*D. meeki,* W. & S.), and *Zygospira* n. sp. (without radial plications). In the lower beds of the upper member, a short distance above the top of the thick massive limestone member of the formation, were the following fossils: *Streptelasma* n. sp. (with trilobate calyx), *Dalmanella testudinaria* var., *Rhynchotrema increbescens ?, Trochonema umbilicata ?, Trochonema* sp. undet., and *Cyrtoceras* sp. undet. (near *C. lysander*). All these forms are of Richmond age.

A complete section of the Bighorn limestone is well exposed in Wolf Creek canyon. Lying on the basal sandstone are about 200 feet of massive, cream-colored, silicious limestone, typical of the lower portion of the formation. This is overlain by the top member of purer, softer limestones in part very fine grained and yielding *Rhinidictya, Dicranopora* near *fragilis, Ptilotrypa obliquata, Pachydicta* sp. undet., *Primitia* sp. undet., and numerous corals, a fauna of approximate Richmond age. On Big Goose creek similar rocks are found, 160 feet of massive limestone lying on the basal sandstone and containing only a few maclurinas and coral fragments. This is overlain by the top member, comprising 10 feet of fine grained cream-colored limestone, 42 feet of massive, hard, light cream-colored limestone, in part sandy and with small calcite geodes, 4 feet of coarse grained limestone filled with corals, including *Halysites gracilis* (small-meshed form) and *Columnaria thomii* Hall (like *C. alveolata* Goldfuss, but with separate corallites), 6 feet of sandy and pure limestone layers alternating, and 40 feet of limestone, mostly soft, slabby, and fine grained. Next above are 135 feet of massive cream-colored limestones, cherty in lower part, belonging entirely or in greater part to the Madison limestone, but containing only a few indeterminate coral fragments.

On South fork of Rock creek, 12 miles northwest of Buffalo, large numbers of fossils are weathered out of the reddish clay, due to the weathering

of the uppermost limestone beds of the Bighorn formation. The fossils obtained at this locality, as determined by Mr E. O. Ulrich, are as follows:

Streptelasma rusticum Billings.
Streptelasma cf. *robustum* Whiteaves.
Streptelasma n. sp. (with trilobate calyx).
Lindstromia n. sp.
Favosites asper D'Orbigny.
Proboscina (near *Frondosa*, Nicholson).
Monotrypella quadrata Rominger.
Batostoma manitobense Ulrich.
Bythopora striata Ulrich.
Lcioclemella sp. undet.
Rhinidictya sp. nov.
? *Goniotrypa lateralis* Ulrich.
Sceptropora facula Ulrich.
Plectambonites n. var. or sp. (near *sericea*).
Leptæna nitens Billings
Strophomena n. sp. (between *S. neglecta* and *S. planodorsata*).
Dalmanella meeki Winchell and Schuchert (? Miller).
Dalmanella tersa Sardeson.
Dinorthis n. sp. (distinguished from *D. subquadrata* by its coarse ribs) Hall.
Plectorthis whitfieldi Winchell (small variety).
Rhynchotrema per lamellosa Whitfield.
Rhynchotrema n. var. of *increbescens* Hall.
Lophospira (cast) sp. undet.
Cylora depressa ? Ulrich.
Eurychilina manitobensis Ulrich.
Primitia lativia Ulrich.
Schmidtella sp. undet.

From extensive exposures of the top member of the Bighorn limestone near the head of Lee creek, 14 miles east-northeast of Tensleep, Mr Ulrich obtained the following species: *Halysites gracilis, Columnaria alveolata, C. halli* var., and *Calapœcia* resembling *huronensis* and *anticostiensis,* an association regarded as Richmond. At a horizon 5 feet lower the following species were collected: *Streptelasma rusticum, Leptæna* cf. *nitens, Rhynchonella ? argenturbica ?, Liospira* cf. *micula, Lophospira acuminata, Helicotoma* cf. *marginata,* and a small *Straparollus*-like shell, a Richmond faunule. About 50 feet lower in the same vicinity there was found in the massive limestone member a *Platystrophia* of new species, but believed to be the same as one found in the Trenton limestone of Tennessee.

OCCURRENCE OF THE FISH REMAINS

The fossil fish were discovered in the basal sandstone of the Bighorn mountains, in August, 1905, at various points in the south-central portion of the uplift. They were first observed in outlying buttes on the head of the main or south prong of Red fork of Powder river, 23 miles slightly south of west of Mayoworth post-office, in the southern portion of Johnson county, near the line of Bighorn county. This locality is near the crest of

the Bighorn mountains. They were also found to occur at frequent intervals southward for the next 7 miles to the southern margin of the Bighorn formation, which is on the headwaters of another branch of Powder river, 15 miles northwest of Barnum post-office, in the southeastern portion of Bighorn county.

The relations at the locality first mentioned above are shown in the following section:

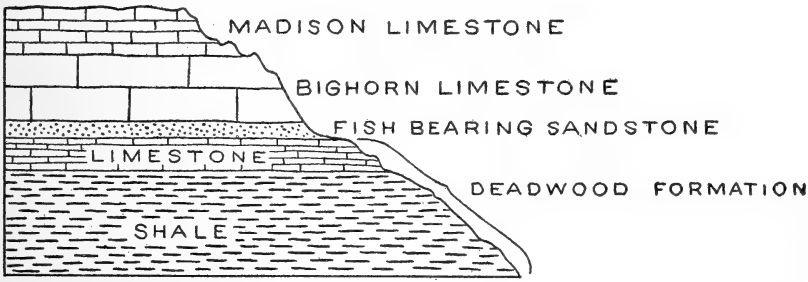

FIGURE 3.—*Cross-section of Butte near Summit of Bighorn Mountains, 23 Miles West of Mayoworth, Wyoming.*

The sandstone at this locality is from 6 to 8 feet thick, and it outcrops frequently. It is moderately coarse grained, varies from hard to soft, is massive, and in part shows considerable cross-bedding. Its color varies from dirty buff to light gray, and many of the weathered portions are brownish. Some portions appear oolitic, owing to concretionary growth of the sand grains. The contacts above and below are sharp, but with no marked evidence of unconformity. The underlying beds are Deadwood limestones and shales, the former containing flat pebble conglomerate of intraformational type. A short distance below the contact fossils occur, consisting mainly of *Dicellamus politus* in large numbers and a few trilobite fragments, apparently *Ptychoparia owenii*, which are characteristic of the Middle Cambrian. The overlying massive limestone is typical Bighorn limestone, containing occasional maclurinas and corals. There can be no question as to the stratigraphic position of the fish-bearing sandstone below this limestone, for the superposition is plainly exposed here as well as at many localities northward. The Bighorn limestone is here only about 40 feet thick, or one-eighth its thickness in its maximum development in the northern portion of the Bighorn uplift. As explained above, the diminished thickness apparently is due somewhat to thinning of the original deposit, but mainly to the absence of the upper portion removed by erosion prior to Carboniferous time. The overlying Madison

limestone of Lower Carboniferous age lies unconformable upon it, but without any marked erosional features.

AGE OF BIGHORN FORMATION

The paleontological evidence, as above presented, indicates that the massive limestone constituting the greater part of the Bighorn limestone is of Trenton age, but it probably represents only the earlier part of the Trenton limestone of other regions. The fish-bearing sandstone is correlated with the Harding sandstone of Colorado, which, as will be shown later, is believed to represent the Black River limestone, so that it is in practically conformable succession with the massive limestone. The upper limestone member of the Bighorn formation, apparently not everywhere present, is of Richmond age or separated from the massive limestone by a hiatus representing later Trenton, Utica, Eden, and Lorraine time, and perhaps also the earliest part of Richmond time. According to present ideas the later Richmond represents the last of Ordovician time, so that the hiatus above the Bighorn limestone when the Richmond representative is present is equivalent to Silurian and Devonian times. The unconformity between the Bighorn and Deadwood formations represents the Upper Cambrian and a long period of early Ordovician, comprising Beekmantown, Lower Magnesian, and Saint Peters.

Ordovician in Owl Creek Mountains

The Bighorn limestone, which is so conspicuous in the northern portion of the Bighorn uplift, appears extensively in the Owl Creek mountains, but with diminished thickness. Near the canyon of Bighorn river, which is at the east end of the range, the thickness is only 40 feet, but in the vicinity of Phlox mountain, 30 miles west, and Owl Creek canyon it is over 150 feet thick, and in the vicinity of Crow creek, at the south end of Shoshone mountains, it is about 100 feet. The formation outcrops continuously around the higher central area of the Owl Creek uplift and westward along the South fork of Owl creek to a point 3 miles west of longitude 109 degrees. It outcrops again on the slopes adjoining the Crow Creek canyon and the upper portion of West fork of Muddy creek and in Bighorn canyon. The most prominent exposures are in the great south and west facing escarpment of Phlox mountain, where its cliffs are nearly 150 feet high.

The formation consists almost entirely of a massive limestone, usually of light buff color, somewhat darker when weathered, filled with a coarse mat or network of irregular silicious masses, mostly from one-half to 1 inch in diameter. On weathering, this silicious material stands out a

FIGURE 1.—WEATHERED BIGHORN LIMESTONE SHOWING CHARACTERISTIC NETWORK OF SILICA

The area in view is about 4 by 5 feet. Photograph by C. D. Walcott

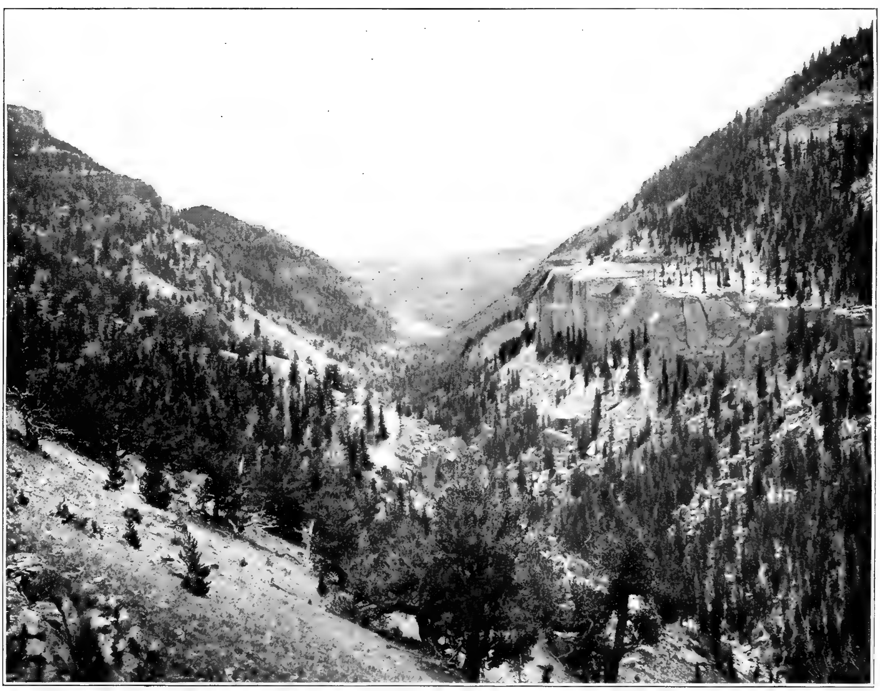

FIGURE 2.—BIGHORN LIMESTONE IN CANYON OF OWL CREEK, NEAR LONGITUDE 109°

View is taken looking down the canyon. The limestone constitutes the high cliff on the right. The smaller cliffs are Madison limestone

EXPOSURES OF BIGHORN LIMESTONE

half-inch or more on the rock surface as a ragged network, the purer rock between having been dissolved. This feature and the very massive bedding are as characteristic here as in the Bighorn mountains. In the canyons the formation gives rise to steep walls, presenting almost continuous outcrops of the formation, a feature strikingly exhibited in Owl Creek canyon as shown in figure 2, plate 76. Here the massive limestone is overlain by 20 feet of white, broken limestone capped by a 20-foot massive bed similar to the thick limestone below. At the top of the formation there are a few feet of sandstone and shale, which are directly overlain by Madison limestone. In places the upper beds weather to a reddish tint, strongly suggestive of the member of Richmond age, which occurs in the northern portion of the Bighorn uplift. In figure 1, plate 77, is shown the basal contact of the massive limestone with the Deadwood shales, the top Deadwood limestone being absent.

Very few fossils were found in the Bighorn limestone in the Owl Creek mountains, and these were fragments of maclurinas and corals similar to those in the Bighorn mountains.

Ordovician in Northwest Wyoming and Montana

West of the Bighorn basin lie the Absaroka and Shoshone mountains, consisting of Tertiary rocks, mainly igneous, which cover the older formations. In an outlying range known as Cedar and Rattlesnake mountains, west of Cody, the lower Paleozoics appear and the Bighorn limestone is present. It has been studied by Mr C. A. Fisher,* who states that the thickness is 150 feet and the formation presents its usual character and stratigraphic relations, excepting that the reticulating network of silica on the weathered surface of the rock are less pronounced than in the Bighorn mountains. The upper portion of the formation consists of thin bedded limestone not sharply separable from the overlying Madison limestone. Outcrops occur in canyons of the Shoshone river, Clark fork, and Pat O'Harra, Little Rocky, Bennett, and Line creeks.

On the east slopes of the north end of the Absaroka range there is an extensive development of Paleozoic rocks, which has been described by Mr Arnold Hague in the Absaroka folia.† On the Cambrian (Gallatin limestone) lies the Jefferson limestone, which is classed as Silurian, but no satisfactory paleontologic evidence of its age was obtained. From the descriptions given in the folio this limestone appears not to closely resemble the Bighorn limestone exposed lower down Clark fork and in

* C. A. Fisher: Geology and water resources of the Bighorn basin, U. S. Geol. Survey, Professional paper no. 53.

† U. S. Geol. Survey, Geologic atlas of the United States, folio no. 52, 1899.

Shoshone canyon 30 to 35 miles east and south. Another dissimilar feature in the section also is the presence of an overlying limestone (Three forks) containing Devonian fossils. The Jefferson limestone extends along the various ranges of the Rocky mountains in central Montana, lying between the well defined Middle Cambrian limestone and Devonian limestone or shales (Three forks) and having a thickness of from 150 to 300 feet. Its color is dark, the bedding mostly massive, constitution a dolomite, and the lower beds give rise to a prominent ledge or cliff. In the Absaroka range, as described in the folio above cited, a few poorly preserved fossils were found in the lower beds of the Jefferson limestone, but they appeared to be species which "might occur high in the Cambrian or near the base of the Silurian (Ordovician). In the same way, at other localities, the species procured from near the summit of the terrane are such as possess a wide vertical range and might be found as low as the Silurian, but at the same time are known to occur elsewhere with typical Devonian species." It has been suggested that the Jefferson limestone may comprise a continuous series of sediments from Cambrian to Middle Devonian in age, but in the absence of positive paleontologic evidence its stratigraphic range can only be surmised. Perhaps a close examination will reveal unconformities representing long time intervals. However, it is possible or even probable that the Jefferson limestone includes the Bighorn limestone in whole or in part, and Ordovician fossils will be found in it in some portions of Montana.*

Ordovician in Western Wyoming

During the examination of the Owl Creek Mountain region a few observations were made on the east slope of the Wind River range, where the Bighorn limestone was seen occupying its usual position between Deadwood and Madison formations. No detailed study was made nor fossils obtained, but the limestone is 200 feet thick and presents its usual characteristics.† Undoubtedly it is the same limestone that yielded

* Descriptions of the Jefferson limestone are given in U. S. Geol. Survey folios 1, 24, 30, 52, and 56; Bulletins no. 110, pp. 25-29, and no. 139, pp. 37-38; Eighteenth Annual Report, part iii, pp. 468-470, and Twentieth Annual Report, part iii, pp. 287-289.

† In a preliminary examination of the Wind River range in 1906, I found the massive silicious limestone member of the Bighorn formation west of Lander about 100 feet thick and underlain by a thin bed of sandstone, partly calcareous, which contains large numbers of fossils. These have been determined as follows by Mr E. O. Ulrich:

Receptaculites oweni, Hall; *Streptelasma* cf. *profundum*, Conrad, and *corniculum*, Hall; Ramose bryozoan, agreeing in general aspect with *Callopora multitabulata*, Ulrich; *Plectambonites sericeus* var.; *Dalmanella testudinaria* var.; *Strophomena* n. sp. near *S. sulcata*, Verneuil, and *S. fluctuosa*, Billings; *Ctenodonta* cf. *levata*, Hall; *Cyrtodonta* cf. *rotulata*, Ulrich; *Psiloconcha* n. sp.; *Archinacella* cf. *A. deleta* (Sardeson) and *A. subrotunda*, Ulrich; *Protowarthia* cf. *cancellata* (Hall); *Lophospira* near *L. elevata*,

Halysites catenulatus to Comstock in 1873,* for its features and relations accord with the descriptions. A thickness of 150 feet was reported west of Camp Brown. Professor Comstock, however, classified the formation as Niagara on the old supposition that the Halysites was characteristic of that age. Some observations as to the extent of this formation in the Wind River range and some other ranges west and northwest were made by Professor St. John, of the Hayden survey.† In the Teton region the same formation is described by this observer (page 480, Eleventh Report) as follows:

"Niagara: Heavy bedded, buff, magnesian limestone, usually weathering in castellated exposures 400 feet and less to 600 feet. In the southwest occurs a local development of light colored, rough weathered quartzitic sandstone 50 feet or more in thickness, apparently occupying the place of the dolomite limestone. Also local developments of drab shales, 100 feet more or less, occur in this horizon."

On the map of "Part of central Wyoming" in the atlas to the Twelfth Hayden Report the formation is included in beds designated "Calciferous series," which ends near the southeastern termination of the Wind River range at a point about 4 miles north of Sweetwater river.

Ordovician in the Black Hills Uplift

The Ordovician is represented in the Black Hills uplift by a formation known as the Whitewood limestone. This has a thickness of 80 feet in the vicinity of Deadwood, in the northern Black hills, but it thins rapidly to the southward and disappears near Elk creek on the east side and at the head of Rapid creek on the west side of the hills. The rock is hard, massive, somewhat silicious, and ordinarily of buff color with brownish spots or mottlings. It contains large Endoceras, Maclureas, and corals of Trenton age. It appears prominently in the Nigger Hill and Bear Lodge uplifts, with a thickness averaging 60 feet. The manner in which the formation thins out in the middle and southern portions of the Black

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Ulrich; *Trochonema umbilicatum*, Hall; *Hyolithus* cf. *baconi*, Whitfield; *Chiton canadensis*, Billings; *Orthoceras* near *O. Olorus*, Hall, and *O. nicolletti*, Clarke; *Actinoceras* cf. *remotiseptum*, Clarke (septa less distant).

Mr Ulrich regards this fauna as of late Black River or early Trenton age, indicating equivalency with the basal sandstone of the Bighorn formation in the Bighorn mountains and with the Harding sandstone near Canyon City, Colorado.

* Report upon the Reconnaissance of Northwestern Wyoming, made in the summer of 1873, by William A. Jones (War Department), 43d Congress, 1st Session, H. R., Ex. Doc. 285, Washington, 1874, p. 112.

† Twelfth Annual Report of the U. S. Geol. and Geog. Survey of the Territories for 1878, part 1, Washington, 1883, pp. 173-269, and Eleventh Report of the U. S. Geol. and Geog. Survey of the Territories for 1877, Washington, 1879, pp. 325-508.

Hills uplift has not been ascertained. Possibly there is a general thinning of all the strata, but it is probable that there is simply a beveling off by pre-Carboniferous erosion, so that the lowest layer extends farthest south. Whether the formation was originally deposited in the southern Black Hills region and subsequently removed by erosion or whether its absence is wholly due to non-deposition is not ascertained. In its upper and lower contacts the only evidence of unconformity which the formation presents is the abrupt change of materials. In the Deadwood region there is, at its top, a small thickness of greenish shales in which no fossils have been found. These shales give place abruptly to the basal limestone (Englewood formation) of the Pennsylvania division of the Carboniferous (see figure 2, plate 77). The Whitewood limestone lies unconformably on the Middle Cambrian, overlapping to the south and west onto lower beds than those on which it lies near Deadwood.

Absence of Ordovician in Laramie Mountains

No evidence of the existence of Ordovician rocks is presented in any portion of the Laramie mountains, including also the Casper and associated ranges. There are frequent exposures in which Carboniferous rocks lie directly on the granites and schists, although in the northern portion of the district there is an intervening sandstone which may be either Carboniferous, Cambrian, or even Ordovician. No fossils were found, but from its character and relations it is supposed to be Carboniferous, probably Pennsylvanian.

Absence of Ordovician in Hartville Uplift

In the Hartville uplift lying between the Laramie range and the Black hills the limestones of the Mississippian division of the Carboniferous lie on Algonkian rocks, and Ordovician, as well as Silurian, Devonian, and Cambrian, are absent.

Ordovician in Eastern Colorado

General Extent and Relations

Along the east slope of the Rocky mountains there is a nearly general overlap of Upper Carboniferous deposits onto the pre-Cambrian rocks, but a few small areas of earlier Paleozoic rocks appear. These areas are in the embayments west of Colorado Springs, west and north of Canyon City, and in Perry park. The Ordovician rocks exposed consist of limestones and sandstones usually lying on a thin mass of Cambrian sandstone, or

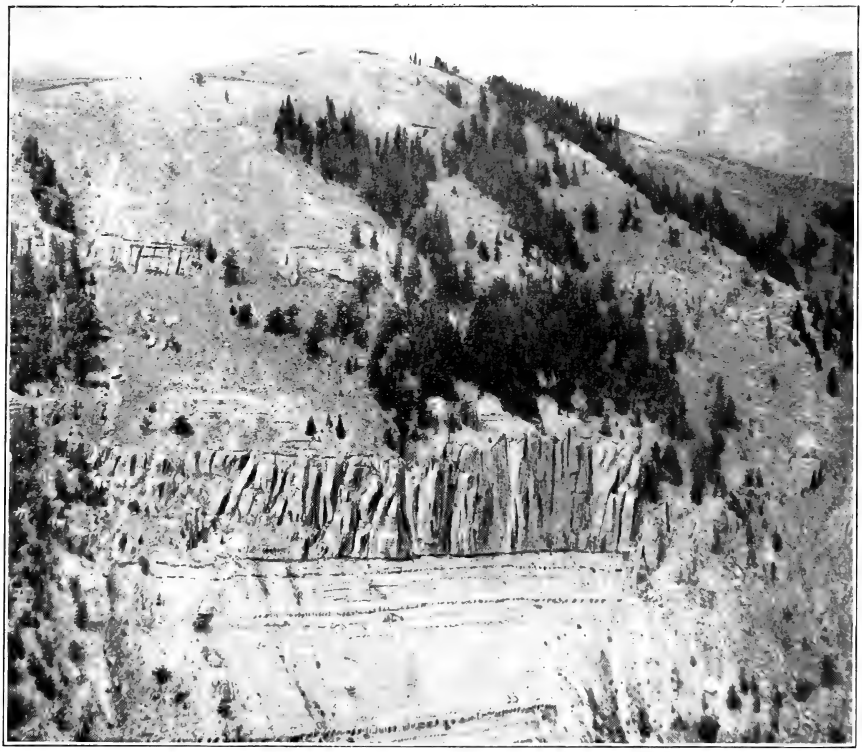

FIGURE 1.—BIGHORN LIMESTONE ON DEADWOOD SHALE, OWL CREEK CANYON, 2 MILES WEST OF LONG. 109°

Upper half of section is Madison limestone. South end Shoshone mountains in distance to right

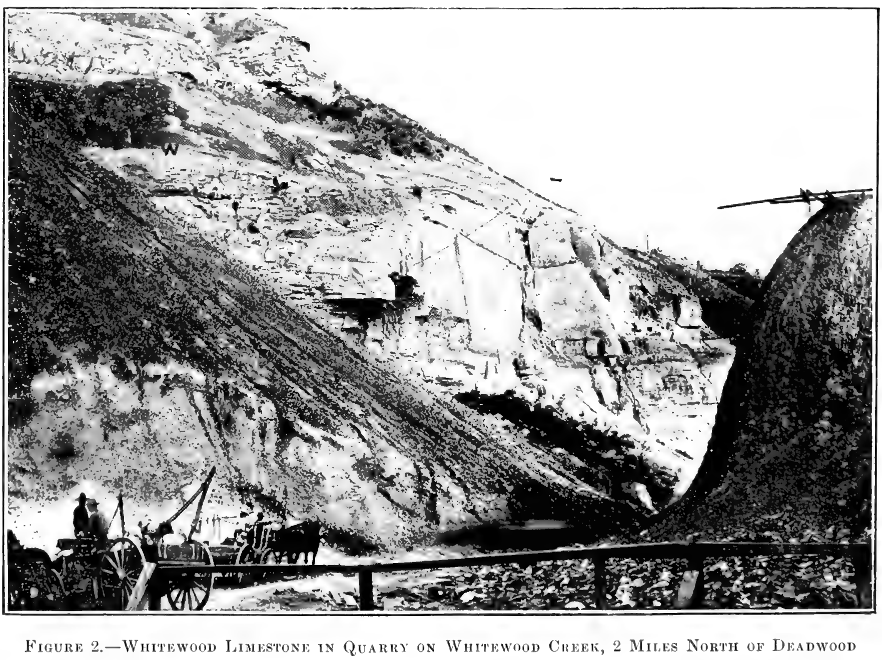

FIGURE 2.—WHITEWOOD LIMESTONE IN QUARRY ON WHITEWOOD CREEK, 2 MILES NORTH OF DEADWOOD

All below the W is Whitewood limestone, above which are green shales and then Parhasapa (carboniferous) limestone. Photograph by T. A. Jaggar, Jr.

EXPOSURES OF BIGHORN AND WHITEWOOD LIMESTONES

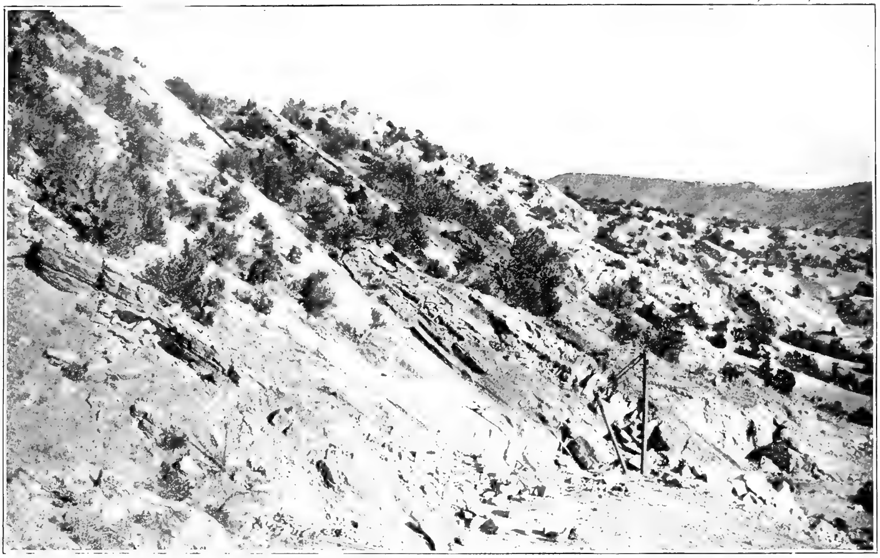

FIGURE 1.—ORDOVICIAN ROCKS ON EAST SLOPE OF ROCKY MOUNTAINS NORTHWEST OF CANYON CITY, COLORADO

Looking north. Granite to left, Harding sandstone in quarry, slopes of Fremont limestone, Millsap limestone, and Red beds to right. Photograph by C. D. Walcott

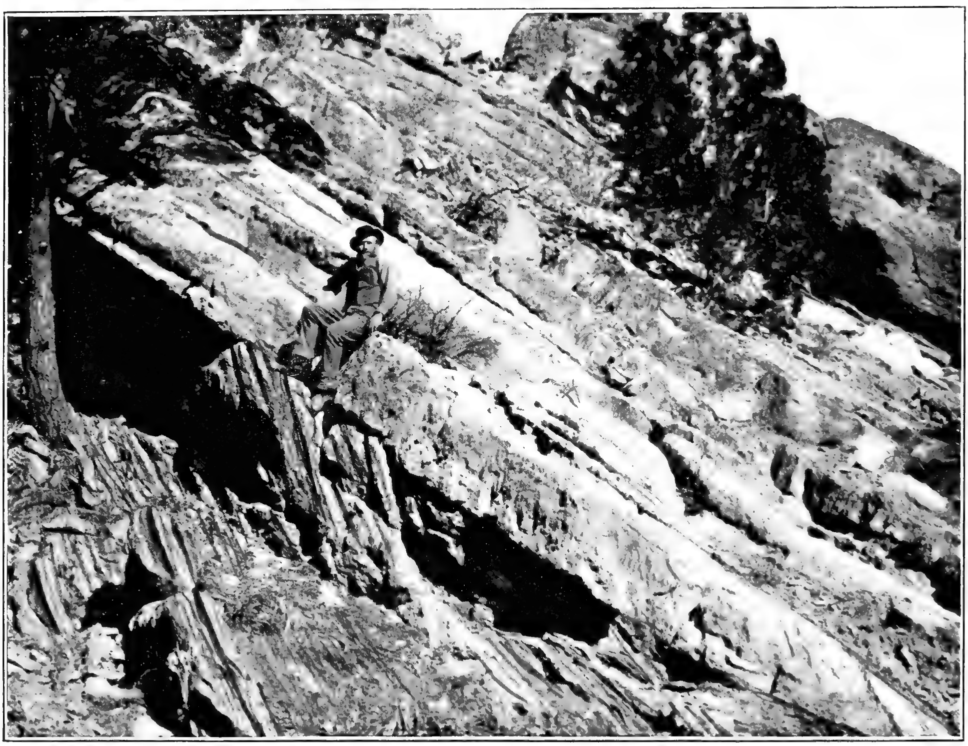

FIGURE 2.—HARDING SANDSTONE LYING ON GNEISS WEST OF CANYON CITY, COLORADO

The man's feet are on the contact. Photograph by C. D. Walcott

EXPOSURES OF ORDOVICIAN ROCKS AND HARDING LIMESTONE

quartzite, and sometimes they overlap on the granite and gneiss. The overlying formation, separated by unconformity generally, is the Millsap limestone of Lower Mississippian age.

In the region about Canyon City the Ordovician is represented by the Manitou limestone, Harding sandstone, and Fremont limestone. These have been described in detail by Mr C. D. Walcott* mainly in connection with the occurrence of fish remains, and by Dr Whitman Cross in describing the region northeast of Canyon City which is included in the Pikes Peak folio. I have made a detailed examination of the outcrops west and southwest of Canyon City.

MANITOU LIMESTONE

This limestone is extensively exhibited in Oil Creek valley, Garden park, a few miles north of Canyon City, where it consists of fine grained pink or reddish dolomite less than 100 feet thick. It also occurs in the Manitou region, where it contains Ophileta, Camerella, and other characteristic Ordovician fossils. It often is underlain by cherty, reddish limestone and sandy beds containing Cambrian fossils.

HARDING SANDSTONE

This formation consists mainly of fine, even grained, granular sandstone in alternating bands of light-gray and pinkish or variegated colors, with a few bands of dark-red or purplish sandy shale, having a maximum thickness of about 100 feet. The lower part is sometimes calcareous and develops into a thin, fine grained dolomite. This formation contains the fish remains at the Canyon City locality. In Garden park the sandstone rests with apparent conformity on the Manitou limestone, but to the southeast it overlaps on the basal sandstone, and near Canyon City on the gneiss, as shown in figure 2, plate 78. At Canyon City the formation is 86 feet thick, and consists of gray, reddish, and purplish-brown sandstone and shales, with many fossils of early Trenton age. A small outlier of sandstone, apparently of this formation, underlying the Millsap (Carboniferous) limestones in the slopes west of Beulah, is mapped by Gilbert in the Pueblo folio.

FREMONT LIMESTONE

Overlying "the Harding sandstone with apparent conformity there occurs a bluish-gray or pinkish dolomite of uneven grain, sometimes arenaceous, which gives rise to very rough weathered surfaces." Its

* Bull. Geol. Soc. Am., vol. 3, pp. 153-167.

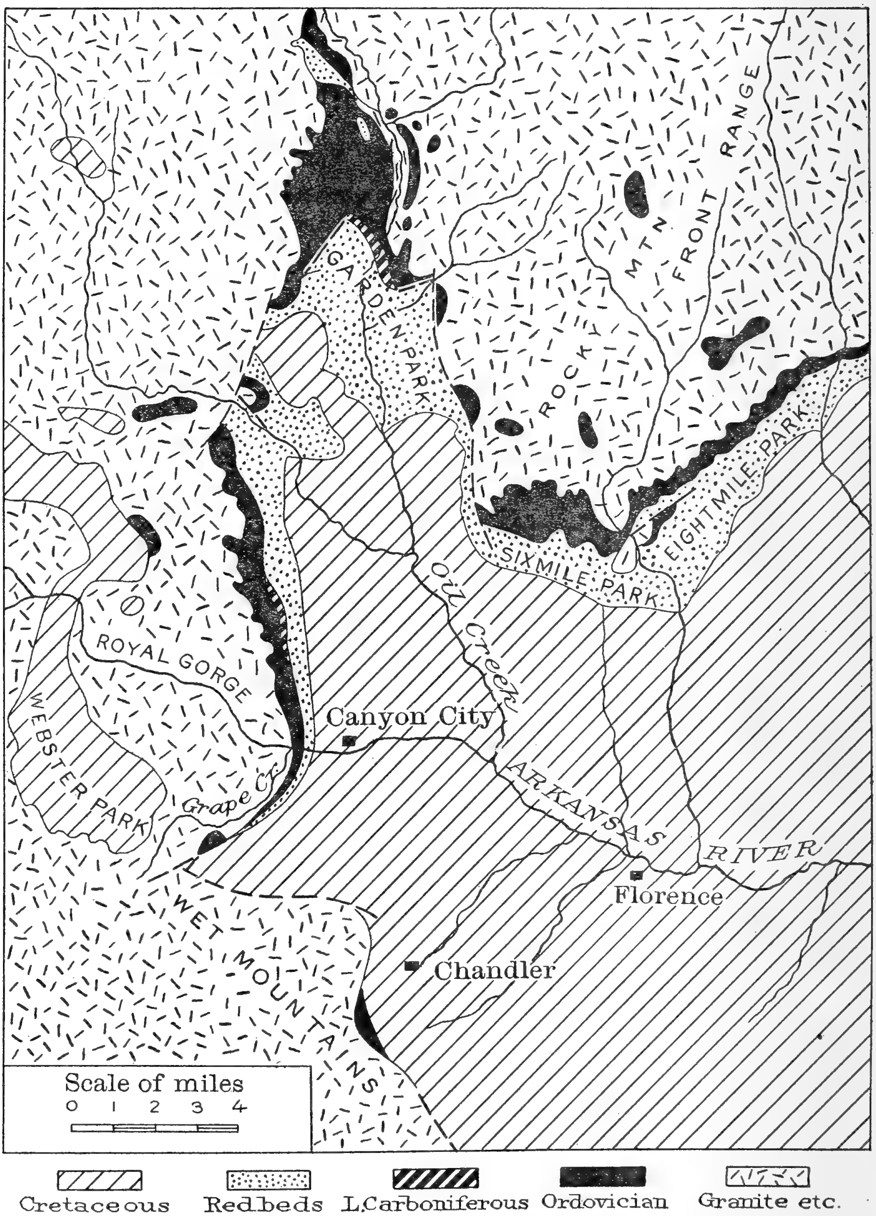

FIGURE 4.—*Sketch Map showing Distribution of Ordovician Rocks in the Canyon City Region, Colorado.*

Partly from Pikes Peak folio, by W. Cross.

thickness in Garden park is about 100 feet, but increases southward to a maximum of 270 feet near Canyon City, partly through the development of an upper fossiliferous member. In Garden park it is characterized especially by the coral *Halysites catenulatus,* and also contains a molluscan fauna like that of the Upper Trenton in New York. It appears to be restricted to a small area in Garden park and vicinity and a narrow outcrop extending southward past Canyon City.

These formations all disappear a short distance southwest of Canyon City by overlap of later deposits and faulting, but two small outlying areas of Harding sandstone overlain by Fremont limestone were found, one near the road 4 miles southwest of Canyon City and another at the foot of the mountain on one of the branches of Chandler creek, 7 miles nearly due south of Canyon City, the latter containing fish remains.

RELATIONS IN GARDEN PARK REGION

The Ordovician limestones and sandstones are extensively exposed on the west side of Oil creek, north of Garden park, a few miles north of Canyon City. At the base is Manitou limestone with a basal cherty and quartzitic portion of Cambrian age lying on the granite and gneiss. Next follows the Harding sandstone, surmounted by long slopes of Fremont limestone. So far as observed, this sequence is general for an extensive area about Garden park. In portions of the area faults cut out some, or all, of the beds. On the granite slopes east of Oil creek numerous small outliers occur. The Manitou limestone is here 100 feet thick, and consists of fine grained pink or reddish dolomite with Ordovician fossils. Cherty limestone at the base yields fragments of the trilobite Ptychoparia of Cambrian age. The Harding limestone consists of fine and even grained saccharoidal sandstone in alternating beds of light-gray or pinkish and variegated colors, with a few bands of dark-red or purplish sandy shale. The maximum thickness is about 100 feet. The lower part is sometimes calcareous and locally develops into a thin, fine grained dolomite. It is succeeded with apparent conformity by the Fremont limestone, which is a bluish gray or pinkish dolomite of uneven grain, sometimes sandy, weathering to very rough surfaces. Its thickness is about 100 feet, and it is especially characterized by the occurrence of chain coral (*Halysites catenulatus*), which often occurs in masses 2 feet in diameter. It also contains other fossils of Upper Trenton age.

The Fremont limestone gives rise to long sloping plateaus on the west side of Oil creek north of Garden park. At the north end of the park the Fremont limestone is overlain by 30 feet of Millsap limestone in a narrow outcrop about 1½ miles long.

Southeast of Garden park lie Sixmile, Eightmile, and Cemetery parks, valleys which mark the eastward and northeastward extension of the Fountain Red beds across the north end of the Front Range anticline. On the north side of these parks are slopes of Ordovician limestones and sandstones, comprising Manitou and Harding, with Fremont as far east as Eightmile creek, northeast of which the Fountain formation lies directly on the Harding sandstone. Outliers of Manitou limestone occur at intervals high on the granite slopes north. Three miles southwest of Garden park is Shaw park, underlain by a zone of Fountain Red Bed outcrops which extend southward to Arkansas river west of Canyon City. On the west side of this zone the Ordovician limestones and sandstones extend far up the mountain slopes, while on the east side is a hogback of Dakota sandstone. At the north end of Shaw park there is a prominent fault, which crosses Wilson creek nearly at right angles and brings formations from Ordovician to Cretaceous into contact with the pre-Cambrian rocks.

RELATIONS WEST OF CANYON CITY

In the mountain slopes and hogback west of Canyon City there is presented the southward extension of the formations of the Garden Park area. The formations all dip steeply to the eastward, and there are numerous exposures of all the beds. The high mountain range west, consisting of granite and gneiss, is traversed by Arkansas river in a deep ridge the Ordovician rocks are extensively exhibited (see figure 1, plate 78).

On the mountain road 4½ miles northwest of Canyon City the Manitou limestone lies directly on the granite. It is 10 feet thick and contains bands of chert. Next above is characteristic Harding sandstone, pink and buff, except at the top, where there is a characteristic succession of reddish shales. The Fremont limestone appears with its usual characteristics, and apparently also the Millsap limestone, although no Carboniferous fossils were observed at this place. The upper portion of the Millsap limestone presents a very irregular contact with conglomerate beds at the base of the Fountain Red beds. In the vicinity of Harding's quarry, 2 miles northwest of Canyon City, the Manitou limestone is seen to have disappeared, and it is not found again in the extension of the beds southward. The following detailed section in this vicinity was made by Mr C. D. Walcott:*

* C. D. Walcott: Discovery of a vertebrate fauna in Ordovician strata. Bull. Geol. Soc. Am., vol. 3, 1892, pp. 155-157.

Geologic Section of Fremont Limestone and Harding Sandstone near Harding's Quarry, northwest of Canyon City, Colorado

	Feet
Fremont limestone:	
Compact, hard, light-gray limestone, breaking into angular fragments, but with a band of purple and gray calcareo-arenaceous shale at the base, containing a large Trenton fauna	45
Dark, reddish-brown sandstone	10
Hard, compact, light colored limestone, with fossils	45
Gray, silicious, magnesian limestone, somewhat ferruginous in lower portion; weathers locally to reddish friable rock, except that near base limestone weathers into rough irregular cliffs with many caverns and holes; corals and other fossils	170
Red and purple fine grained, argillaceous, arenaceous shale; fish-plate fragments (see plate 79)	2–4
Harding sandstone:	
Coarse purplish sandstone in several layers with gray layers above.	11
Gray and buff sandstone	7
Fine grained, argillaceous, arenaceous shale	3
Massive gray and reddish sandstone with thin, irregular beds of reddish-brown, sandy shale in lower portion; numerous fish remains	20
Reddish-brown, sandy shales, partly calcareous in some layers; fish plates and other fossils abundant	7
Compact, thinly bedded, reddish and gray sandstone passing into a gray and more massively bedded, somewhat friable, sandstone that changes at 25 feet up into a purplish tinted, somewhat coarse, friable sandstone; dip 40 degrees	33
Coarse, light-gray sandstone	5
Granite.	

Overlying the Fremont limestone are 15 to 30 feet of impure variegated, banded limestones, with interbedded sandstones and argillaceous beds containing Mississippian fossils. The unconformity between the two limestones—a hiatus representing Silurian and Devonian time—is not marked by discordance of dip nor by any noticeable erosion features. On the north side of Arkansas river, at the mouth of the Royal gorge, the Ordovician beds are well exposed, lying on granite and gneiss and dipping steeply eastward. There is a basal conglomerate merging upward into hard gray to pink sandstones, in part coarse grained, 100 feet or more in thickness. These are succeeded by 80 feet of reddish-brown shales and thinly bedded sandstones, 70 feet of gray to pink sandstones (mostly soft and massive), 8 feet of red shales, 30 feet of gray to pink sandstones (mostly massive), followed by a talus-covered interval of about 100 feet, east of which appear ledges of Fremont limestone merging upward into a few feet of gray sandstone. The latter is overlain by the basal red con-

glomerate of the Fountain formation. On the opposite side of Arkansas river the Harding sandstone is about 200 feet thick and is overlain by about 100 feet of limestones, in part sandy, capped by a 20-foot bed of light-gray sandstone. On the irregular upper surface of the latter lie coarse conglomerates at the base of the Fountain formation. Both the

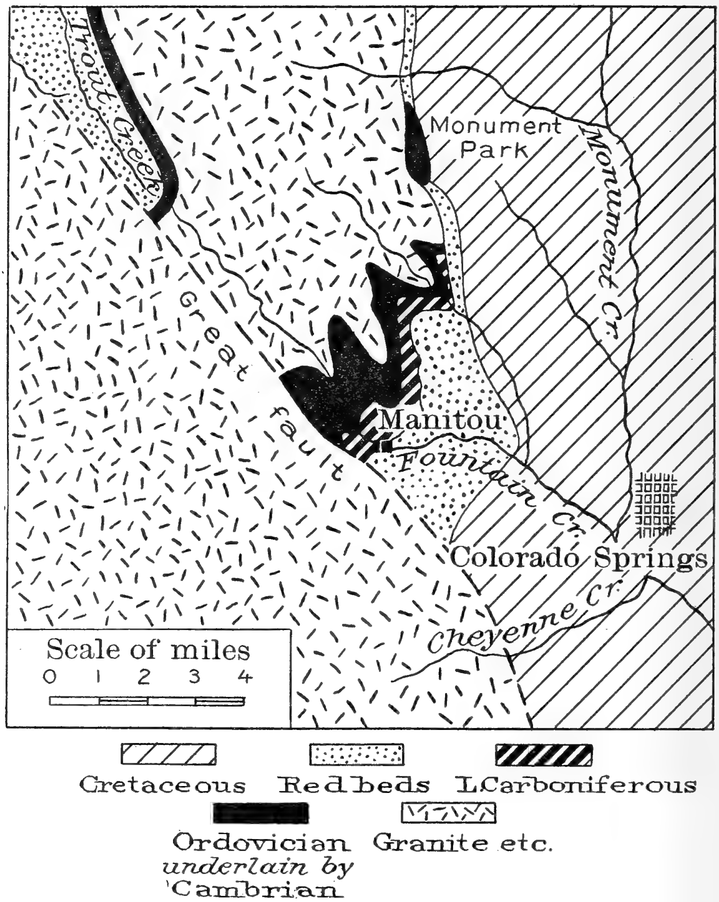

FIGURE 5.—*Sketch Map of Manitou Embayment, west of Colorado Springs, Colorado.*

Harding sandstone and the Fremont limestone end a short distance to the south on Grape creek, the sandstone terminating at a point about three-fourths of a mile south of Arkansas river. The Fountain formation also thins rapidly, and at a point a mile south of the river is only about 250 feet thick.

EXPOSURE OF THE SHALE MEMBER LYING BETWEEN HARDING SANDSTONE AND FREMONT LIMESTONE

Two miles northwest of Canyon City, Colorado. Photograph by C. D. Walcott

On the east side of Grape creek, just above its mouth, there are nearly continuous exposures from the granite to the "Dakota" sandstone. At the base are about 150 feet of massive gray Harding sandstones, pinkish in their upper portion. These are succeeded by about 50 feet of soft gray sandstone, with some layers, 50 feet of limestone (Fremont), 10 feet of red sand and sandstone, and about 900 feet of Fountain Red beds.

Fish Remains and Associated Fossils near Canyon City

HARDING QUARRY LOCALITY

The fish remains obtained by Mr Walcott, near Canyon City, in 1890, occur in the Harding sandstone, which is closely similar in appearance to the fish-bearing sandstone of the Bighorn formation, as described on a previous page. The principal locality is at Harding quarry, which is on the mountain slope 2 miles west of Canyon City, where the section above described was measured. Here the Harding sandstone lies directly on the gneiss, as shown in plate 78. The vertical range of the fish remains is from about 20 feet above the base of the sandstone to its summit, 66 feet higher, and a few occur in the overlying shale (see plate 79). The remains are most abundant in a reddish sandy shale that occurs in irregular bands at several horizons in the sandstone, but they are also irregularly scattered through the latter. The fish fauna includes fragments of a Placoderm closely allied to Asterolepis, numerous scales of the character of those of Holoptychius, and what is considered to be the calcified chordal sheath of a form allied to the recent *Chimæra monstrosa.* In the sandstone occur numerous remains of invertebrates comprising 11 general and 19 species, which are "of the type of the basal Trenton of the New York section." In the Fremont limestone which overlies the thin shale member at the top of the Harding sandstone there is a large and varied fauna which, at a horizon 3 feet above the base, contains 34 genera and 55 species. At a horizon 180 feet higher 33 genera and 57 species occur. "These faunas are respectively of the types of those of the Lower and Upper Trenton faunas of the New York section."

The character of the fauna at the lower horizon is shown by *Receptaculites oweni, Halysites catenulatus, Columnaria alveolata, Strophomena alternata, Streptorhynchus filitextum, S. sulcatum, Orthis biforata, O. flabellum, O. subquadrata, O. tricenaria, Rhynchonella capax* var. *increbescens, R. dentata* Hall, *Ambonychia bellastriata* Hall, *Modiolopsis plana* Hall, *Murchisonia tricarinata* Hall, *Cyclonema bilex, Bellerophon bilobatus* Sow, *Endoceras proteiforme* Hall, *Ormoceras tenuifilum, O. crebriseptum, Orthoceras vertebrale* Hall, *O. multicameratum* Hall, *Gomphoceras powersi* James, *Asaphus* like *A. platycephalus, Illænus crassi-*

cauda, and *I. milleri.* Of these 11 species pass up into the fauna 180 feet above.

MANITOU REGION

At Manitou and for some distance northward and in the Trout Brook valley (Manitou park) Manitou limestone underlies the Fountain Red beds. On Trout brook this limetsone has yielded distinctive Ordovician fossils.

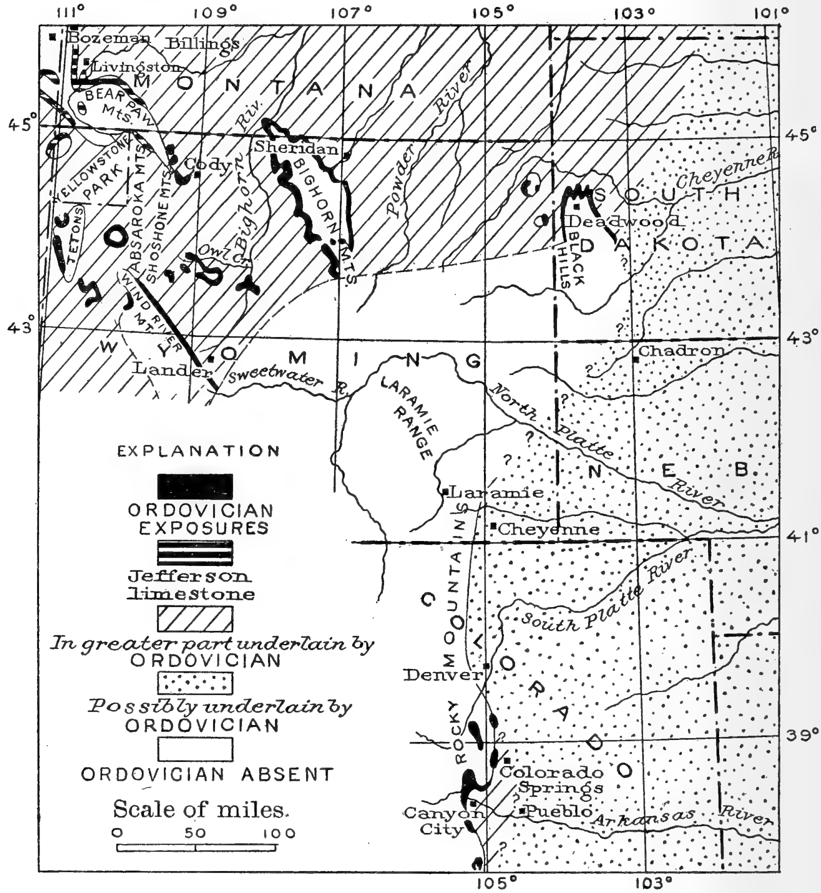

FIGURE 6.—*Map of a Portion of the Northwest, showing Distribution of Ordovician.*

Throughout this area it is underlain by Cambrian sandstone. Near Manitou there are several hundred feet of limestones, of which the lower portion is Manitou, while the upper members, according to A. W. Grabau,*

* G. H. Girty: Carboniferous formations and faunas of Colorado. Professional paper, U. S. Geol. Survey, no. 16, 1903, p. 168.

contain Mississippian fossils. This limestone caps the sloping ridges west and south of Manitou and appears extensively in the intervening canyons, especially in Williams canyon. Its outcrop, together with that of the underlying sandstone, is terminated by overlap of the Fountain formation a mile north of Glen Eyrie, but it reappears in the small embayment west of Monument park. In this latter outlier there are exposed, lying on the granite, 30 feet of dark-gray, coarse sandstones, thin bedded and glauconitic at the top, overlain by 20 feet of bright-red, sandy limestone with Cambrian fossils, and by 50 feet of massive, pure, fine grained, light-gray limestone. On this limestone, which apparently is Manitou, lies an impure limestone varying from gray to buff in color, with a heavy breccia at its base, the latter probably marking an unconformity. The limestones are cut off by a fault, bringing down the Morrison and overlying "Dakota," but a short distance to the north and south the Fountain Red beds are exposed lying directly on the granite.

Doctor Peale gives a section of the exposure of Manitou limestone and associated formations on Camp creek, at Glen Eyrie,* which has 30 feet of limestones, mostly red, believed to be of Ordovician age, separated from the granite by 50 feet of sandstones.

DEADMAN CREEK

On Deadman creek, 6 miles south of Perry park, a small outlying area of Lower Paleozoic rocks has been investigated by Mr Willis T. Lee.† The rocks are cherty limestones in layers interstratified with red clay, overlying a few feet of deep-red quartzite of supposed Cambrian age. The fossils obtained were examined by Doctor Weller, who found the best preserved speciemns to be *Dalmanella testudinaria* of Ordovician age.

PERRY PARK

A second exposure of this limestone, with similar characters, occurs in the southern portion of the Perry Park embayment at the head of the easternmost prong of West Plum creek, as noted by Doctor Peale, of the Hayden survey. Mr Lee found no fossils at this locality.

Résumé

In figure 6 there is indicated the area of outcrops of the Ordovician in a portion of the Northwest, and also the probable underground distribution of rocks of that system. We have little or no light as to the extent of the area of original deposition, for all of the region, at least south of

* A. C. Peale: Geology of the South Park division. Seventh Annual Report, U. S. Geol. and Geog. Survey of the Territories, 1874, p. 201.

† W. T. Lee: Geology of the Castle Rock region, Colorado. Am. Geologist, vol. 29, pp. 96-97.

latitude 45 degrees, was subjected to erosion during Silurian and later times, which may have resulted in the removal of Ordovician rocks in all the area in which they are now absent. At no locality has there been observed evidence of an original margin of the later Ordovician, either by shore deposits or conformable overlap of deposits of the next succeeding system (Silurian). The thinning and absence of the Ordovician rocks and overlap by Carboniferous rocks is in itself no evidence at all, because a great thickness of sediments could have been removed in Silurian-Devonian times, especially along zones of increased uplift. The thinning out of the Bighorn formation in the southeastern portion of the Bighorn mountains apparently is due to the latter cause.

From the foregoing it will be seen that the various maps which have been prepared showing "land areas in Ordovician" times are misleading in the region to which this paper relates. Evidently in much of the region described there were land surfaces in early Ordovician (pre-Trenton) time, for the sandstones underlying the Bighorn and Fremont limestones usually lie unconformably on earlier deposits and show shore-line features. They are widely overlapped by the succeeding limestones, the products of deeper water deposition, but the extent of this deep water is an unsolved problem, for no evidences of its shores have been found. In the central Colorado region at least, the sandstone (Harding) conformably overlies and in places overlaps a somewhat earlier Ordovician limestone (Manitou), which indicates that in places there were deeper or quieter waters preceding those which deposited the sandstone.

It appears probable that the Ordovician rocks west of Colorado Springs and near Canyon City are projections from an extensive area underlying the plains region eastward, as suggested in figure 6. If this exists, its western edge has been eroded and buried beneath the Red Beds-Granite overlap, excepting in the old embayments where protected from erosion.

We have but few data as to the rocks and geologic history of the later Ordovician. The limestones which represent the Richmond occupy an area of considerable size in the central and northern portions of the Bighorn mountains, and are separated from the underlying limestone of Trenton age by a hiatus representing a long interval of time. They may have been deposited extensively in the Northwest and later mostly removed by the widespread post-Ordovician erosion, or, on the other hand, may have been only laid down in restricted basins. Apparently all of the area treated in this paper was a land surface during the interval between Trenton and Richmond times, although there may have been some local areas of deposition in which the rocks now are buried, or from which they may have been removed, prior to Richmond deposition.

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TYPES OF SEDIMENTARY OVERLAP*

BY AMADEUS W. GRABAU

(Presented in abstract before the Society December 29, 1905)

CONTENTS

* This paper, under the title "The interpretation of stratigraphic series by the principles of sedimentary overlap," was awarded the Walker first prize by the **Boston** Society of Natural History in May, 1906.

Introduction

The sedimentary formations of the earth's crust fall readily into two great stratigraphic groups, the marine and the non-marine, which in their essential characteristics are strongly contrasted and which in the analysis of sedimentary series must be carefully differentiated. In spite of the practice to the contrary, stratigraphers will admit that only marine deposits are suited to furnish the record for a complete time scale, and that consequently the standard column of any region should be based on marine deposits only. Where, as is often the case, the column selected as a standard contains non-marine members, the column is imperfect as long as these are retained. Thus the standard Cretacic column of North America is impaired by the retention in it of the non-marine Dakota and Laramie formations, and until recently the standard Triassic section of Germany was practically useless, as it contained only one marine member. The substitution of an extensive series of marine members for the Bunter Sandstein and Keuper has given us a perfect standard of comparison, such as is hardly equaled by that of any other of the geological systems.

Non-marine sediments, however, while not serviceable as members of a standard time scale, are still of great stratigraphic importance, since they furnish us with records of physical changes not determinable from the deposits of the marine series; but as long as non-marine sediments were regarded as lake deposits only, their true significance was overlooked. Now that stratigraphers recognize that non-marine deposits are oftener than not of fluviatile or æolian origin, their real meaning becomes more and more apparent.

The two types of sediment are distinguished from each other not only by their fossil content, but also, and almost as easily, by their physical characters, especially the larger ones. The most striking difference of all lies in the manner in which the successive members of either series are related to each other. In the following discussion the distinguishing

characters of the marine and the non-marine series will be separately treated in the order indicated.

Classification of Types of Overlap

The types of overlap of sedimentary strata may be classified as follows:

A. Irregular or discontinuous overlap.

B. Regular continuous or progressive overlap.

  1. Marine.
     - *a.* Transgressive.
     - *b.* Regressive.
  2. Non-marine.
     - *c.* Fluviatile.

Irregular Overlap

Under this term we may comprise all overlap of concordant sedimentary formations, of any type, which does not proceed regularly in a given direction. All overlaps of strata due to sudden inundations rather than regular invasions belong here; also overlaps due to temporary deposition from any cause, as æolian sediments. Generally this kind of overlap implies some erosion of the underlying concordant formations, thus producing a disconformity. A change of method of deposition may also produce this kind of overlap, as the overlap of the marine Paleozoics along the Front Range region by the non-marine Red beds.

Progressive Overlap

Under this term are included the types of overlap due to a regular progressive onward movement of the zones of deposition, whether the direction of that onward movement is landward, as in a regularly transgressing sea,* or seaward, as in a regularly retreating seashore, and the regular progressive spreading of zones of deposition, as in a growing subaerial fan or dry delta. The first two cases constitute the marine transgressive and regressive; the third the non-marine fluviatile type of progressive overlap. The lake delta may be considered as a local phase of spreading river deposits.

Progressive Overlap in marine Series

The subject of progressive overlap of marine strata may be conveniently discussed under the following headings:

1. Transgressive overlap.

* This is overlap as defined by Geikie. Text Book, 3d ed., p. 518.

2. Regressive overlap.
3. Compound regressive and transgressive overlap.

Transgressive Overlap

When the sea regularly advances upon an old land surface from which there is a continued supply of detrital material, a steadily advancing shore zone of pebbles or sand will be recorded in the sedimentary series which is forming in the transgressing sea. At any given stage in the process a shore deposit of coarse clastics, derived from the old land surface, will form for some distance out, grading seaward into a deposit of finer shore-derived material. In proportion to the distance from the shore the fineness of the material will increase, and at the same time material derived from organic deposits, such as coral reef sands or shell formations, will accumulate in the regions of purer water. With progressive slow advance of the sea, the supply of detritus being uniform,

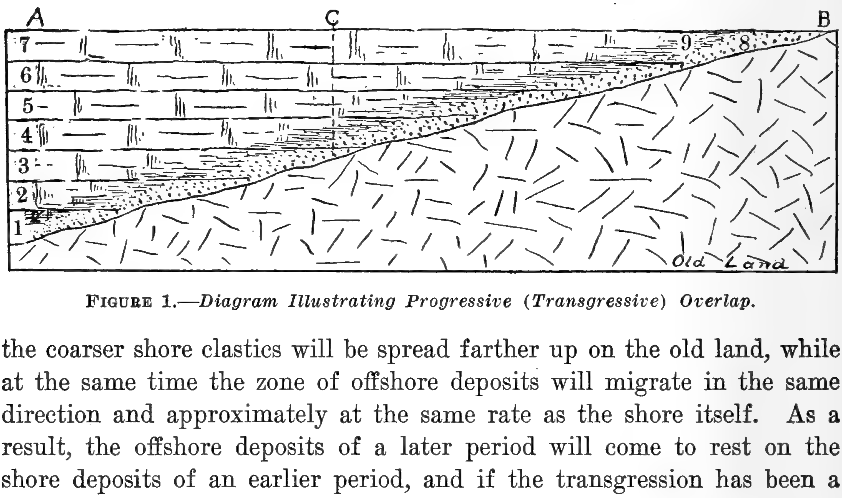

FIGURE 1.—*Diagram Illustrating Progressive (Transgressive) Overlap.*

the coarser shore clastics will be spread farther up on the old land, while at the same time the zone of offshore deposits will migrate in the same direction and approximately at the same rate as the shore itself. As a result, the offshore deposits of a later period will come to rest on the shore deposits of an earlier period, and if the transgression has been a uniform one, on a uniform old land surface, with a uniform supply of detritus, a vertical section of such a series of successive deposits will show an upward gradation from coarse to fine comparable to the similar gradation in texture of the deposit of a single period from the shore seaward. At the same time there will be a continuous basal bed of coarse clastics spread immediately above the old land surface within the zone of transgression, this continuous bed being made up of the shore ends of the successive units of the series formed during the successive periods of the transgression. The basal bed will be essentially a lithic unit, resting everywhere unconformably upon the old land surface, and it will be succeeded upward by strata of similarly uniform lithic charac-

ter in most of the sections. But it is evident from a consideration of the mode of its formation that the age of different portions of this basal bed varies, becoming progressively younger in the direction of transgression. The following diagram will illustrate this principle:

The series of successive strata, 1 to 7, is deposited at *A* during the period of transgression of the sea from *A* to *B,* and therefore it constitutes the depositional equivalent of the time interval occupied by the transgression, which may be assumed to have proceeded at a uniform rate. It is evident that the basal sand or conglomerate bed 1–8 is not of the same age throughout, but rises in the scale progressively, until at *B* it is equivalent in age to bed 7 at *A*. The same thing is true of bed 2′–9, a finer bed which directly succeeds the basal bed, and which like it rises in age in the direction of transgression. It is clear that two sections of this series, taken the one nearer the shore than the other, as at *C* and *A,* will have the same lithic succession from the base upward; but section *C* will begin very much higher in the scale than section *A,* and the corresponding lithic units of the two sections will be of different age.

Application of the Principle of Transgressive Overlap in the sedimentary Series

THE BASAL PALEOZOIC SERIES

General character of the overlap.—Wherever the Paleozoic rocks are found to rest unconformably on the pre-Cambrics, a comparison of sections shows a progressive overlapping of the successive formations, each of which rests, with a basal sand or conglomerate bed, on the eroded surface of the pre-Cambric old land. Some of the more typical examples of this may now be cited.

Newfoundland.—A comparison of the following sections from Trinity and Conception bays, Newfoundland, will show the character of the basal transgression. At Trinity bay, Smith sound, the Lower Cambric (Etcheminian of Matthew) is represented by 811 feet of fossiliferous shales, with some limestones carrying the *Holmia bröggeri* fauna. Almost 350 feet below the top of the Etcheminian is a brick red and pinkish limestone stratum, 27 feet thick, and rich in *Holmia bröggeri, Hyolithes princeps,* and other fossils. This is the Smith Point limestone of Walcott, which has been recognized in Conception, Saint Marys, and Placentia bays. In Conception bay, at Manuels brook, this limestone when found rests directly on the basal conglomerate, which has a thickness of 35 feet, and in its basal portion contains boulders of the underlying gneiss up to 6 feet in diameter; but upward it changes to fine sand.

If the correlation of the Smith Point limestone of the two sections is correct, and if the sections contain no unrecognized faults or erosion planes, we have here a case of progressive encroachment of the sea, apparently from the west eastward, though, of course, the basal gneiss of the Manuels Brook section may represent an old reef or island in the Cambric sea, which was gradually covered by encroachment from all sides. The difference in deposition, however, between these two points is about 300 feet of basal beds, the basal conglomerates of the eastern section being equivalent to the shales 300 feet above the base in the western section and not to the basal beds there. The following diagram illustrates this point:

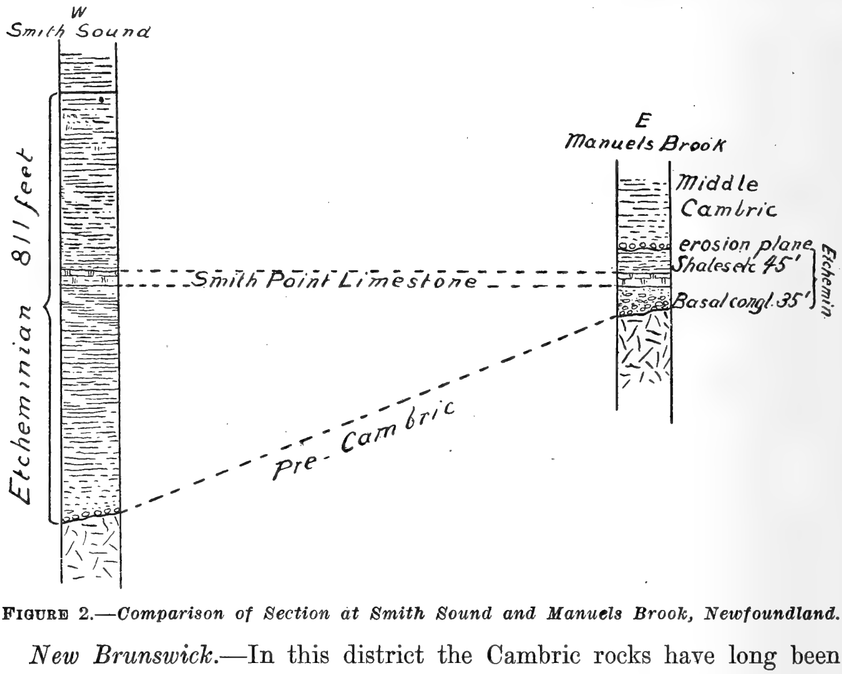

FIGURE 2.—*Comparison of Section at Smith Sound and Manuels Brook, Newfoundland.*

New Brunswick.—In this district the Cambric rocks have long been included under the general term of the Saint John group, from their typical exposure in the region about Saint John, New Brunswick. Matthew has subdivided the series as follows:*

	Feet
Division 3. (Bretonian) at Straight shore, Portland	700
Division 2. (Johannien) at Kings square, Castleton	1,000
Division 1. (Acadian) at Alms house, Simonds	650
Total	2,350

"The coarser sediments found at the base of the Saint John group are largely derived from those older rocks, chiefly the Huronian (Algonkian), and the line

* Illustrations of the fauna of Saint John group.

of division between it (the Saint John group) and the Huronian (Algonkian) is marked by conglomerates of mechanical origin which show no trace of the hardening process by which the Huronian conglomerates and breccias have been so firmly cemented."*

The Acadian represents the lower part of the Middle Cambric and begins with the Saint John quartzite, which is succeeded by the Protolenus zone, and this in turn by the Paradoxides zone. Beneath the Saint John quartzite is a series of red and green sandy shales 150 feet thick, below which lies the red basal conglomerate. Both the red shales and the conglomerate are referred to the Etcheminian or pre-Saint John terrane. This terrane is fully developed at Hanford Brook, Saint Martins, some 30 miles north of east of Saint John, where it is 1,200 feet thick. Here it begins with a coarse purplish red conglomerate 60 feet thick, which rests upon amygdaloidal greenstones of an older (Cold-Brookian) series, and passes upward into sandstones and flags some 300 feet thick, followed by a second conglomerate 35 feet thick, which in turn is followed by shales and sandy shales to the top of the series.

It is evident, then, that we have here an overlapping series, with a basal conglomerate in each case, that of the Saint John region, however, being equivalent, not to the basal bed of the Etcheminian series of the Hanford Brook section, but to the shales of the upper division of that series.

In Cape Breton island the Lower Cambric or Etcheminian strata were found by Matthew to have a thickness of 3,000 to 5,200 feet at Mira bay, on the eastern coast. Twenty miles farther west, on East bay (Bras d'Or lakes), only 500 feet of Etcheminian occurs. Both sections show a basal conglomerate resting on older rocks, succeeded in both cases by Middle Cambric strata, at the base of which an erosion interval is indicated in some other sections.

On the East Bengal road the lower Etcheminian is 3,200 feet thick, decreasing on the West Bengal road to 1,300 feet, and to 270 feet at Dugald brook, on East bay. The upper division likewise increases from 2,000 feet on the East Bengal to 1,700 feet on the West Bengal road, and to 230 feet at Dugald brook. The increase of the lower beds westward appears to be due to progressive overlap of the beds, while the greater thickness of the upper beds in the eastern section, when taken in connection with the heavy conglomerate which lies at the top of the series in the west, seems to suggest retreatal features of the type more fully discussed later on. Of course here, as in all the sections of disturbed areas, the possibility of the existence of faults and folds must be

* Matthew: Fauna of Saint John group, pt. 1, 1882, p. 87.

taken into consideration, since we can never be absolutely certain of the accuracy of the sections made in such regions. The general correspondence of the facts to the requirements of the theory seem, however, to suggest that the correlations as here given are correct.

In comparing the Myra valley section with the Lower Cambric strata of eastern Newfoundland (811 feet at Trinity bay, 80 to 100 feet at Manuels brook, or even the greater thickness of 1,200 feet at Hanford brook), the discrepancies are such as can not readily be accounted for by differential rate of deposition. In respect to the Trinity and Conception Bay sections, it has already been shown that the difference is in part accounted for by progressive overlap, and the progressive disappearance of the lower members. But this is not altogether the case, since there is a difference of nearly 300 feet in the beds above the Smith Point limestone. This, however, is accounted for in the Manuels Brook section by an erosion interval, as shown by the conglomerate at the base of the next succeeding Middle Cambric, the pebbles of this conglomerate being derived from the underlying Etcheminian. In the Smith Sound (Trinity Bay) section, however, deposition appears to have been continuous from lower to middle Cambric time, since no erosion interval is recorded. Walcott, moreover, correlates the basal 130 feet of the Middle Cambric of this section with the Protolenus beds of New Brunswick. If this correlation is correct, the eastern Newfoundland section represents only the upper part of the New Brunswicktown (Hanford Brook) section. The same reasoning would lead us to regard both the eastern Newfoundland and New Brunswick sections as representing only the upper part of the sections shown in eastern Cape Breton. This conclusion is, of course, based on the supposition that no very pronounced unrepresented interval occurs at the top of the Etcheminian in either the eastern Newfoundland or the New Brunswick section.

Northern Appalachian area.—In eastern Labrador and western Newfoundland Lower Cambric strata rest with basal conglomerates and sandstones (often arkoses) upon the gneisses and other pre-Cambric rocks. They pass upward into shales and limestones, of which over 1,700 feet are exposed at Bourne bay, Newfoundland. The fauna of these beds is the typical Olenellus fauna of the Appalachian province. Upward these strata are succeeded by nearly 1,500 feet of limestones, with some shales and a quartzite near the base, all of unknown age, while above there is 400 feet of limestone carrying a lower Ordovicic fauna. At Canada bay, Newfoundland, 2,500 feet of conglomerates, shales, and igneous rock form the base of the Cambric series and are succeeded by nearly 3,000

feet of limestones, shales, and intercalated sandstones carrying the Olenellus fauna.*

In northern Vermont the Lower Cambric consists of over 2,000 feet of limestones and shales with the Olenellus fauna, but the base of the series is not exposed. Southward, in the slate belt, the maximum thickness of the Lower Cambric is estimated by Dale† to be 1,400 feet, at Hebron mountain. The base is not exposed and the upper part is formed of quartzite and sandstone ranging in thickness up to 100 feet. Then follows 1,000 to 1,200 feet of Lower Ordovicic, the Middle and Upper Cambric series being apparently absent.‡ On the flanks of the Green mountains the basal Cambric beds are sandstone, resting unconformably on the pre-Cambric gneiss. These are the granular quartz of the Vermont geologists, which were long ago referred to the Potsdam on account of their position. The thickness of the quartzite is estimated at from 800 to 900 feet,§ and about 470 feet of the overlying Stockbridge limestone is also referred to the Lower Cambric.‖ This makes a total of 1,370 feet for the maximum of the Lower Cambric in the Green Mountains section. Compared with the Highgate Springs section, the base of the Green Mountains section seems to be considerably higher in the column, since in the northern Vermont section the basal beds are not shown. Walcott has suggested that the great mass of argillite east of the Vermont Central Railroad track in the Georgia section may be older than the limestone at the base of the section.¶ If this is the case, the Vermont section becomes more than double the thickness now assigned to it. In any case it is likely that the basal granular quartz of the Green Mountains is the time equivalent of the upper portion of the limestones of northwestern Vermont.

Southern Appalachian area.—The Hardyston quartzite of New Jersey represents the basal member of the series in the northern part of the southern Appalachians. It rests on the pre-Cambrics of the Highlands and varies from a few feet to over 200 feet, probably owing to the irregularity of the pre-Cambric floor.** It is often feldspathic and occasionally a conglomerate. It frequently grades up into the overlying Kittatinny limestone, which has an estimated thickness of from 2,700 to

* Murray: Geological Survey Rept. of Newfoundland, 1864.

† Nineteenth Ann. Rept. U. S. Geological Survey, pt. iii, p. 178.

‡ This appears to be true of the Middle Cambric in the northern Vermont region, though coarsely conglomeratic limestones with Upper Cambric fossils occur here. On the whole it seems that the northern Appalachian trough was dry land during Middle Cambric time, the sea returning only in Upper Cambric time.

§ Pumpelly, Wolf, and Dale: Monograph 23, U. S. Geological Survey, 1896, p. 190.

‖ Dale: Fourteenth Ann. Rept. U. S. Geological Survey, 1895, p. 541.

¶ Bulletin 30, U. S. Geological Survey, 1886, p. 19.

** Weller: Paleontology of New Jersey, vol. iii.

3,000 feet, and is mostly Cambric in age, though the upper beds carry an undoubted Beekmantown fauna. No Middle Cambric fossils have been recognized in this limestone, but an Upper Cambric fauna occupies at least the upper third, exclusive of the portion referable to the Beekmantown. In Pennsylvania a basal Cambric sandstone has been observed in a number of localities resting upon the pre-Cambrics. In the Cumberland valley this bed, known as the Reading quartzite, is probably near the horizon of the Hardyston quartzite, while the Cumberland limestone is in general the equivalent of the Kittatinny. The latter is separated, in New Jersey, by an erosion interval from the Trenton which follows it; its upper limit is therefore not of the same horizon everywhere. Whether or not the same is true of the Cumberland has not been ascertained. The basal sandstone is well shown at the Chickies (Chiques) rock on the Susquehanna above Columbia (Lancaster county), from which locality it takes its name. From the occurrence in it of Scolithes it was formerly referred to the Potsdam by Lesley.* At Emigsville a typical Olenellus was found in the sandstone.† Its thickness is estimated at 1,300 feet, though this may be excessive.‡ It is succeeded by 1,500 feet of limestones, the upper portion of which carry Ordovicic fossils.

At Balcony Falls, Virginia, 300 feet of sandstones and slates, with a basal conglomerate bed, form the basal Cambric series (Chilhowee), throughout most of which fossils of the Olenellus series occur. At Monterey and along the Blue Ridge mountains over 4,000 feet of quartzites, sandstones, shales, and mottled limestones occur, containing the Olenellus fauna. These are overlain by the Shenandoah limestone, the lower part of which is Middle and Upper Cambric. At Harpers Ferry the Chilhowee series is subdivided as follows:§

	Feet
Shenandoah limestone.	
Chilhowee series:	
Antietam sandstone	500
Harpers shale	800 to 1,200
Weverton sandstone	100 to 900
Loudon formation—slates, sandstones, conglomerates, and limestone—maximum	800
Unconformity.	
Catoctin schist (Algonkian).	
Total Chilhowee	3,400

* Lesley: Second Geological Survey of Pennsylvania, vol. x, 1885, pp. 16-17.
† Walcott: Loc. cit.
‡ Bascom: Bull. Geol. Soc. Am., vol. 16, p. 298.
§ Harpers Ferry folio.

In the region about Knoxville, Tennessee, the Shenandoah becomes known as the Knox dolomite and has a thickness of 3,500 feet. Beneath it, southeast from Bays mountain, is from 8,000 to 9,000 feet of shales and limestones, with occasional sandstone members, which are especially prominent toward the base, where extensive conglomerates occur.*

The series comprises:

	Maximum thickness Feet
Knox dolomite	3,500
Nolichucky shale	550
Marysville limestone	550
Rogersville shale	220
Rutledge limestone	450
Rome formation (shales)	250
Rome sandstones	700
Beaver limestones	300
Apison shale	1,100
Hesse sandstone	500
Murray shale	300
Nebo sandstone	500
Nichols shale	800
Cochran conglomerate	1,600
Sandrock shale (with Starrs conglomerate lentils farther southwest)	1,000
Total Chilhowee	8,820

Farther to the northwest† all the formations between the Rome and the Knox dolomite are represented by the Conasauga shale series, with a thickness of from 600 to 800 feet. This may be a nearer-shore formation, and the diminished thickness from 1,280 (minimum) or 2,770 (maximum) to 600 or 800 feet may be due to a rise of the top of the sandstone member underlying, which, from lithic similarity, is here also called Rome. Owing to the non-exposure of the base, the exact relation of these beds to the underlying pre-Cambric land surface can not be determined. In western Virginia‡ all the members above the Rome formation are shown with slightly increased thickness. The lowest formation is the Russell sandstone, 1,400 feet thick, but without exposure of the base; so we do not know whether the Russell is a basal bed or whether the lower beds are concealed. Since these beds are along the strike of the strata, as shown in the Knoxville folio, it seems probable that they are of the same age, and that hence the equivalent lower beds occur in the embed of this region.

* Keith: Knoxville folio.

† Briceville folio.

‡ Rome, Tazewell, Bristol, Estillville, Morristown, and Briceville folios.

Southeastward from western Virginia, the Rutledge, Rogersville, and Marysville formations are replaced by the Honaku limestone, a siliceous limestone aggregating perhaps a thousand feet in thickness.

The foregoing sections demonstrate that the transgression of the Cambric sea, in which the strata now preserved accumulated, was toward the *northwest* in the southern Appalachians.

South central section.—In Oklahoma and Indian Territory the Wichita and Arbuckle uplifts have exposed the basal Paleozoics. Here the basal sandstone member, sometimes wanting, is the Reagan sandstone, varying up to 500 feet in thickness. It is succeeded by the Arbuckle limestone, over 4,000 feet thick, of which perhaps the lower 1,000 feet are Cambric.* The following basal section occurs in the Arbuckle mountains:

Ordovicic

Simpson Formation

	Feet
Greenish shales and thin crystalline and shelly limestones, interstratified with a number of beds of sandstone, one of which, near the middle of the formation, is from 100 to 200 feet thick. The lower division carries a fauna similar to the Chazy of New York and Canada, while the fauna of the upper division is closely related to that of the upper Stones River group of Tennessee and Kentucky and the Stones River formation of the upper Mississippi valley. Thickness......	1,200 to 2,000
Slight erosion disconformity and local deposits of pure sand.	

Cambro-Ordovicic

Arbuckle Limestone

	Feet
Thinly bedded shaly limestones, with sandy beds at the top, grading down into light blue and white limestone and cream colored to white crystalline dolomite, with occasional thin shaly strata and occasional siliceous and cherty beds. The age of the formation varies from Middle Cambric to Lower Ordovicic, including the whole of the Upper Cambric and the Beekmantown formations. "From the base of the formation upward to the top of the Middle Cambrian the rocks are composed of thin bedded and in part intraformational conglomerate and shaly limestones." This comprises several hundred feet, while the Upper Cambric includes about 700 feet of strata.† Ulrich holds that an erosion interval occurs at the top of the Middle Cambric, but the evidence given for that is not conclusive. In the upper 1,250 feet fossils of the Beekmantown horizon occur. Thickness..............................	4,000 to 6,000

* J. A. Taff and E. O. Ulrich: Professional paper no. 31, U. S. Geological Survey.

† C. N. Gould: Geology and water supply of Oklahoma. U. S. Geological Survey Water Supply paper no. 148.

Cambric.

Reagan Sandstone

	Feet
Calcareaus sandstones, thin bedded and laminated, grading downward into clays and greensands, with coarser sands lower down, which pass downward into quartzites and arkose conglomerates of poorly assorted granitic material. At the top of the sandstone and in the shaly and calcareous strata for several hundred feet above the sandstone (basal part of Arbuckle), fossils of Middle Cambric age occur. The thickness averages 300 feet, but varies from almost nothing to	500

Great unconformity, with irregular erosion surface.
Granite and porphyry.

The occurrence of Middle Cambric fossils in the Reagan sandstone marks the beginning of the time of sedimentation as Middle Cambric and probably as the early portion of that period. There is, then, an overlap from the southeast, where the basal sandstone and a considerable part of the limestone is of Lower Cambric age.

In the Ozark region the following section of the basal Paleozoic rocks is exposed:*

				Feet	Feet
Ordovicic	Lower	Potosi group.	Joachim limestone	0 to	150
			Crystal City sandstone	0 to	200
			Jefferson City limestone	50 to	250
			Roubidoux formation	70 to	225+
Cambric	Upper		Gasconade limestone	450 to	650
			Elvins formation	0 to	120
	Middle		Bonneterre limestone	200 to	500 ?
			La Motte sandstone	0 to	300

Great unconformity.
Archean granites and porphyry.

The La Motte sandstone constitutes the basal formation of this section and was formerly identified as Potsdam sandstone. It is frequently a coarse grit or conglomerate near the base, the pebbles being quartz or granite and porphyry, and in the Saint Francis Mountain region a conglomerate of porphyry pebbles lies at the base of the formation. Upward the La Motte becomes more thinly bedded and flaggy, and calcareous beds make their appearance, the transition to the overlying Bonneterre being gradual. The sandstone may disappear altogether, probably along

* Bain (H. Foster) and Ulrich (E. O.): The copper deposits of Missouri. Bull. no. 267, U. S. Geological Survey.

more elevated portions of the old land surface, which, being kept free, on subsidence, from sand accumulations, received directly the deposits of the limestones, which thus overlap the basal sand.

The Bonneterre beds are granular, highly magnesian limestones, often with chlorite in the basal portion. The contact with the underlying formation seems to be a gradational one, indicating continued subsidence, and therefore advance of the sea. The shaly portion contains *Lingulepis* cf. *lamborni*, together with some other fossils, which are regarded as fixing the age of this bed as probably Middle Cambric.

An erosion interval is believed by Ulrich to separate this formation from the next overlying Elvins formation, though the evidence is meager. It consists of an irregularity at the top and the presence of one or more beds of limestone pebbles. The Elvins formation is Upper Cambric, according to its fossils. It consists of shales, shaly limestones, and more or less earthy dolomites. Locally the contact with the overlying Potosi group appears to be disconformable, but in other cases there seems to be a gradation upward into the Potosi.

The Potosi is on the whole a shallow-water and perhaps in part continental deposit with conglomeratic layers, sun-cracked beds, and local erosions. The lower beds are dolomitic limestones, while sandstones of a more or less lenslike character occur in the middle portion, sometimes amounting to beds of considerable extent and uniformity (Roubidoux formation). Upward the series is again terminated by a dolomitic limestone (Jefferson City limestone), which in turn is succeeded by the Crystal City sandstone, with occasionally an erosion disconformity between the two. The Joachim limestone, however, which overlies the Crystal City sandstone, forms a continuous depositional series with it.

While the significance of the basal section appears to be marred by the occurrence of planes of erosion disconformity, it seems nevertheless true that the basal sandstone in this section has risen until it probably lies nearer the top than the bottom of the Middle Cambric series. There seem to have been elevations in the Ozark dome at stated intervals, which caused partial retreat of the sea, followed by a readvance. This is the meaning of the numerous intercalated sandstone beds.

The Upper Mississippi area—Subdivisions.—In eastern Wisconsin the subdivisions of the basal Paleozoic are, according to Chamberlin, as follows:*

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* Geology of Wisconsin, vol. 2, p. 295.

	Feet
Lower Magnesian.	
Saint Croix series.	
6. Madison sandstone	35
5. Mendota limestone (including shale and sandstone)	60
4. Sandstone (calcareous)	155
3. Bluish shale (calcareous)	80
2. Sandstone (slightly calcareous)	160
1. Sandstone (very coarse, non-calcareous)	280
Total	770

Northward the lower members disappear by overlap of the higher. The Mendota bed (number 5) is the fifth Trilobite bed of Owen, with *Dicellocephalus minnesotensis, D. pepinensis, Lingula aurora,* and *L. mosia.*

The section at the Saint Croix Dalles has been studied in great detail by Berkey.* He recognized the following subdivisions:

Magnesian series (Hall and Sardeson).	Shakopee dolomite.			
	New Richmond sandstone.			
	Oneota dolomite.			
	Jordan sandstone.			The Saint Croix formation (Winchell).
	Saint Lawrence dolomites and shales.			
Basal sandstone series (modified from Norton).	3. Franconia sandstone (100 feet).			
	2. Dresbach shales (150 feet).	*Obolella polita* zone.	Greensands and shales.	
		Lingulepis pinnæformis zone.	Calcareous and pyritiferous shales.	
	1. The lowest formation of this series is not exposed in the Dalles area, but it includes the lowest sandstone beds and possibly also the "Hinckley sandstone" (0 to 1,000 feet).			

The Jordan sandstone of this section is correlated by Winchell with the Madison sandstone of Wisconsin. At the Dalles of the Saint Croix it contains a considerable fauna, listed by Berkey,† including *Dicellocephalus osceola.* The Saint Lawrence shales are correlated with the Mendota beds of Wisconsin (fifth trilobite bed of Owen), and include, besides a considerable fauna,‡ *Dicellocephalus minnesotensis* and *D. pepinensis* Owen. The Franconia, or third trilobite bed of Owen, contains a rich trilobite fauna,§ and so does the Dresbach, though this fauna is quite distinct from that of the overlying bed. The species here agree more closely with those of the Potsdam of New York, with which Hall and Sardeson correlate this and the Franconia sandstones. The thickness of this basal series at Minneapolis is nearly 1,550 feet.‖

* American Geologist, vol. xx, p. 377.
† Ibid., vol. 21, p. 270.
‡ Berkey: Loc. cit., p. 271.
§ Berkey: Loc. cit., p. 272.
‖ Hall and Sardeson: Bull. Geol. Soc. Am., vol. 3, p. 338.

Lake Superior sandstone.—This formation is generally referred to the Upper Cambric and correlated with the Potsdam of New York and the Saint Croix of the upper Mississippi valley. From a consideration of the facts furnished by the preceding sections, the progressive advance of the Cambric sea over the North American continent has become apparent. The advance was comparatively gradual, progressing through most of Cambric time and not reaching the upper Mississippi valley until the end of that period. It is therefore most likely that the basal beds of the Lake Superior region mark a higher level than those of the Saint Croix area, and their correspondence to the lower Magnesian series is not improbable. In fact, from their position it seems that they are more readily referable to the Lower Ordovicic than to the Upper Cambric. The section of this region is, however, complicated by the retreat and readvance of the Ordovicic sea, of which the Saint Peter sandstone is the record. This will be more fully discussed under another section of this paper, and therefore the consideration of the equivalency of the basal sandstone of the Lake Superior region is deferred. A few local sections, however, may be added here, to show that in places at least this sandstone is much higher even than basal Ordovicic.

Encampment d'Ours.*—On this island in the south channel (Lake Huron) the base of the section is formed by the quartzites and slates of the Huronian series, upon which rest unconformably 100 feet or more of light colored soft, sometimes conglomeratic, sandstone. This is succeeded conformably by 60 feet of shales and limestones. The lower beds of this series are "prevalently arenaceo-calcareous shales of a dusky green or bluish color." They contain the following species:

Species of the lower Bed	*Range Elsewhere*
Camarotoechia plena Hall	Chazy.
Rafinesquina alternata (Conrad) small var.	Chazy to Richmond.
Cyrtodonta huronensis Bill	Stones River to Trenton.
C. subtruncata	
Vanuxemia inconstans Bill	Black River to Trenton.
Matheria tener Bill	Trenton.
Liospira eugenia (Bill.)	Black River.
Orthoceras multicameratum Emmons	Stones River to middle Trenton.
O. granulosum Rominger	
Stictopora ramosa Hall	Stones River.
Callopora ramosa (D'Orbigny)	Lorraine.
Columnaria cystoceras, etcetera.	

* Rominger: Report on Paleozoic rocks of Upper peninsula of Michigan. Michigan Geological Survey, vol. i, pt. III, 1873, p. 64.

This fauna is clearly of early Trenton (Black River) or Chazy age—a fact which makes the underlying sandstone more nearly equivalent to the Saint Peter of Minnesota (transgressional portion; see beyond) than to any part of the basal sandstone series of the Upper Mississippi region.

On Sulphur island higher strata rest upon the Huronian quartzites without the intervention of the sandstones.* This, as suggested by Rominger, very likely represents a submerged reef or mound of the Baraboo type of Wisconsin; but this does not seem to be the case in the Encampement d'Ours section, where a great thickness of strata, comparable to the basal Superior sandstone, succeeds the Huronian. There can be little question that at this portion of the shore the Middle Ordovicic strata overlapped the Cambric and rested with a basal sandstone on the pre-Cambric. The reference of this bed to the Cambric is clearly erroneous.

On the island of Lacloche (Cloche island) a similar reddish, greenish, and whitish sandstone, from 20 to 30 feet thick, rests on the pre-Cambric crystallines. It passes upward into arenaceous dolomites and limestones with an abundance of fossils, which first appear in the upper layers of the sandstone and which clearly establish the age of the formation as Black River. The probable identity of this sandstone and that on Saint Joseph and Encampement islands with the Saint Marys sandstone of Sault Sainte Marie was early pointed out by Logan, who considered it improbable that these sandstones are the equivalent of the Potsdam of New York.

From a number of localities a siliceous dolomite varying up to 100 feet in thickness has been recorded as lying above the Superior sandstone; this formation, named the Hermansville limestone by van Hise and Bayley,† is generally regarded as of Beekmantown age, though the evidence for this is by no means conclusive. In the Iron Mountain region Upper Cambric fossils are recorded from the basal sandstone, but this does not prove that the basal sandstone of Marquette and the pictured rocks is of the same age. In fact, from their position with reference to the transgression of the Cambric sea, these more northern sandstones must be regarded as of later age than that of the Menominee district. If the Hermansville limestone (Auxtrains formation would be a better name, from the more typical exposure on that stream) proves eventually to be Beekmantown rather than Chazy (that is, Upper Stones River or Lowville), the late Cambric or early Ordovicic age of part of the Superior sandstone must be conceded. In that case, however, the basal sandstone of Sault Sainte Marie and eastward is of much later age, belonging to

* Rominger: Loc. cit.

† Menominee folio.

post-Saint Peter time, the great Saint Peter hiatus separating it from the basal sandstone of Cambric age.

Western Adirondacks and Canada.—Along the western flanks of the Adirondacks the Lowville (upper Chazy) overlaps the preceding formations and rests with a basal sandstone upon the crystallines. This sandstone grades upward through a calciferous sandrock into the purer limestone. The calciferous member has been compared with *the* Calciferous or Beekmantown of the Mohawk and Champlain valleys, with which it agrees in lithic character; but it is evidently a much higher member of the Ordovicic series. This basal bed is traceable northward to the Frontenac axis, on the west side of which, as at Kingston, Ontario, it is a well marked basal sandstone—the Rideau. This sandstone was formerly regarded by Canadian geologists as Potsdam, and the overlying formation has been referred to the "Calciferous" (Beekmantown), with which it agrees in lithic character. The occurrence in these overlying beds of Black River fossils, however, proved this correlation to be erroneous, and Ami suggests that the basal sandstone bed may be the shore equivalent of the Chazy. Wilson,* on the other hand, thinks it is the basal arenaceous member of the lower Black River; and this is probably more nearly in accord with the facts.

In this section and elsewhere in Canada the Trenton limestones (Black River) have been found to rest in places directly upon the crystallines without intervention of basal beds. This fact, as in the case of Sulphur island, is probably to be explained by assuming a slowly submerged island or reef of small extent, from which, in the deepening sea, the siliceous clastics would be removed by the agitated waters.

On the whole, it may be confidently asserted that it is extremely improbable that Potsdam or other Upper Cambric formations occur in Ontario west of the Frontenac axis or east of the Sault Sainte Marie, and that the basal sandstone in all this region is therefore of later age, probably in most cases of late Chazy or early Trenton.

East of the Thousand islands the Potsdam sandstone of New York has been traced northward to the Ottawa, and then eastward past Montreal, along the Saint Lawrence. In some localities along this line the fossiliferous limestones of the Beekmantown overlap the basal sandstone and rest directly upon the crystallines. In typical exposures the Potsdam grades up into the Beekmantown or Calciferous, the fossils of which are types found near the middle of the Beekmantown of the Champlain valley. At Prescott and Maitland nearly 80 feet of limestones, shales, and sandstones overlie the Potsdam, and the lower portion of this series carries

* A. W. G. Wilson: Canadian Record of Sciences, vol. ix, 1903, p. 132.

Scolithes canadensis. The section terminates with a concretionary bed, which at Grenville, where these fossiliferous beds rest directly upon the crystallines, is followed conformably by Chazy. Unless there is an unrecognized hiatus here, the Calciferous of this section represents only the uppermost Beekmantown of the Champlain valley, where this formation has a thickness of 1,800 feet, according to Brainard and Seeley.* If this is the case, then the Potsdam of this series, since it forms a continuous series with the Beekmantown beds overlying, is also of Beekmantown age; for it is hardly conceivable that under apparently uniform conditions 1,800 feet of limestones should accumulate in the Champlain valley, while less than 100 feet accumulated in the Ottawa region. Even if a hiatus exists between the Beekmantown and Chazy of the Ottawa River sections, we can still regard the Calciferous and Potsdam of these sections as above the base of the Beekmantown of the Champlain valley, since the fauna is more comparable to that of the later Beekmantown of the Champlain valley. If this deduction is sound, it leads us to question the Cambric age of all the Potsdam of the Ottawa river and the Rivière du Nord. The fossils found in this basal sandstone are the worm tube *Scolithes canadensis,* and the peculiar tracks called Protichnites, besides *Lingulepis acuminatus, Ophileta compacta, Pleurotomaria* cf. *lawrentina,* and fragments of Orthoceras. The species of gastropods are also characteristic of the Calciferous of these regions, in which formation also occurs a species of Scolithes. *Lingulepis acuminata* is not strictly a Cambric fossil, for the species is found to range up into the Beekmantown at Whitehall, New York, and in Saint Lawrence county. *Ophileta compacta* also occurs in the upper beds of the Chateaugay section in what is considered typical Potsdam sandstone, associated with *Lingulepis acuminata, Dicellocephalus* sp.?, and *Ptychaspis* sp.?†

One hundred and fifty miles up the Ottawa from Grenville, at the Allumette rapids, near Pembroke, the Chazy rests with a basal conglomerate upon the gneiss, and at Saint Ambroise the Trenton rests upon the crystallines with only 20 feet of sandstones intervening. This sandstone has been referred to the Potsdam, but it is more probably referable to the lower Trenton.

Basal Paleozoic beds of the Rocky Mountain region.—Wherever the Paleozoics are exposed in contact with the crystallines, a basal sandstone or conglomerate forms the base of the series. In a number of localities this basal sandstone (Sawatch quartzite) carries a Dicellocephalus fauna, as in Gunnison county (Crested Butte), at Aspen, the Eagle river and

* Bull. Amer. Mus. Nat. Hist., vol. iii, 1890, no. 1, pp. 2, 3.
† Walcott: Correlation papers, Cambrian, p. 343, 347.

Tenmile districts, at Leadville, and elsewhere. At Manitou park 100 feet of sands lie between the fossiliferous Ordovicic limestones and the granite. In the upper bed of this sandstone series Lingulepis and Obolus have been found, on the strength of which discovery these sandstones are referred to the Cambric. At another point in the Park the thickness of this series is 86 feet, while in still another section 40 feet of sandstone intervene between the granite and the Ordovic limestone.

The section at Perry park was examined by the writer. On the granite lie about 100 feet of sandstones, with some cherty limestones, followed by a thin bed of brecciated rock in which the fragments are limestone and chert. This is immediately succeeded by a cherty limestone carrying Carbonic fossils and referable to the Milsap limestone of Cross. The brecciated bed may indicate a line of disconformity, which would justify the reference of the basal sands to the Upper Cambric. On the other hand, the bed referred to shows no evidence of so extensive an erosion interval as would be necessary to make the basal bed Cambric. There seems to be no valid reason why we should not return to the earlier view, namely, that these basal beds are also Carbonic, resting by overlap directly upon the granite. If this is the case, this sandstone is probably not continuous with the basal sandstone of Manitou, the overlap being of the irregular instead of the progressive type.

Another section was examined by the writer in Williams canyon, near Manitou Springs, and a detailed analysis of the beds was made. The basal portion was also examined in Queens canyon. In both cases limestones with Ordovicic fossils were found a short distance above the basal sandstone, of which there are 48 feet in Williams canyon and less than half that amount in Queens canyon. At Canyon City, Walcott found the Harding sandstone resting unconformably on the Algonkian gneiss and miscaceous schist. The base is a 5-foot bed of coarse light gray sandstone, followed by sandstones becoming gradually more reddish and purplish and containing a Lower Trenton molluscan fauna. With these occurs the remarkable fish fauna characteristic of this formation.* Elsewhere in this region, however, Lower Ordovicic limestones and basal sandstones referred to the Cambric occur below the Harding.

The basal sandstones of the Front range, except in such cases as the Harding sandstone, are generally regarded as of Upper Cambric age. That some of these sandstones are of later age than Cambric, representing the continuous encroachment of the sea into Ordovicic time, can hardly be questioned. In fact, from the character of the few fossils found in the limestones immediately overlying, there is some reason to believe that in

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* Walcott: Bull. Geol. Soc. Am., vol. 3, 1892, pp. 153-172.

the Manitou Springs region the basal sandstone is Lower Ordovicic rather than Cambric. That continued encroachment of the sea caused the overlap of the Ordovicic is shown in a number of cases along the Front range.

In the Sangre de Cristo range the Arkansas sandstone of Carbonic age overlaps the Lower Paleozoics, resting for the most part directly on the granite foundation of the range. This case, however, is probably not an example of progressive overlap, but of the irregular type.

Foreign examples.—The basal Paleozoic section of the north of Scotland furnishes a record of nearly continuous subsidence, and therefore of progressive advance of the sea on the land of that period. Resting uncomformably on the pre-Cambric Torridon sandstone is a basal conglomerate with pebbles up to an inch in diameter, made of the underlying material. This passes upward into cross-bedded sandstones and arkoses, which in turn grade upward into the "pipe rock," a fine quartzite penetrated by numerous worm tubes (Scolithes sandstone, Eriboll quartzite). These basal clastics, probably in part non-marine, are from 450 to 600 feet thick, and are succeeded by mudstone, the so-called Fucoid beds, in which calcareous sediment first appears. This is the beginning of the granular dolomite which becomes most characteristic of the upper beds. The dolomites, with a thickness of perhaps 1,500 feet (calciferous sandrock or Durness limestone series of Scottish geologists), ranges in age from Cambric to Lower Ordovicic. The calcareous beds bear evidence of accumulating in quiet water, yet there is near the middle of the series a cross-bedded sandstone, which indicates an interruption and temporary return of shore or dry land conditions, after which offshore sedimentation again took place in this region.

This section, then, indicates that a progressive subsidence took place (interrupted by the interval referred to), and that hence we must look somewhere for successive overlapping of the beds and the rise of the basal clastics in the series. The record of overlapping has been destroyed by erosion in the northern area, but in Wales we still find traces of it. In southern Wales the basal beds of the Cambric are conglomerates, sandstones, and shales, with lower Cambric fossils, and 1,570 feet thick (Caerfai group). They are succeeded by 1,800 feet of sandstones and slates, with mid-Cambric fossils (Solva group), and higher still by 750 feet of shales and grits, with *Paradoxide daudis* and *P. hicksii* (Menevian). These are followed by the Lingula flags (2,000 feet), and are later succeeded by the Tremadoc slates (1,000 feet), which are regarded by British geologists as forming the top of the Cambric, but are classed by continental geologists with the basal Ordovicic. There is a record of subsidence here, but the subsidence is not so marked, nor is the shore zone

removed to the extent shown in northern Scotland. The deposits here, aggregating 7,000 feet in thickness, are terriginous throughout. In western England the Cambric beds have a more offshore character, consisting of basal sandstones, followed by calcareous beds and by the Dictyonema and Shineton shales. There are some intercalated conglomerates, and the thickness of the series is much less than in Wales, thereby indicating some oscillating conditions. On the whole, however, there seems to have been a steady advance of the sea westward.

In northern Wales the lowest Cambric beds are the Llanberis slates, 3,000 feet thick, and the Harlech grits, a continental formation 6,000 feet thick. This is followed by 225 feet of Menevian, and then by 3,100 feet of the Lingula flags (Upper Cambric), which in turn are succeeded by the Tremadoc (1,000 feet). The Llanberis slates rest upon quartz felsite, and have furnished *Conocoryphe* and *Hyolithes*. They are most probably to be classed as Middle Cambric, which fixes the transgression as of that data in north Wales. The transgression reached Anglesea, in northwestern Wales, toward the close of Cambric time; for here the pre-Cambric crystallines are succeeded by basal quartz-jasper conglomerates of Tremadoc age,* all the earlier beds having come to an end and being overlapped by the highest of the series. The fossiliferous Tremadoc beds pass upward into beds with Arenig fossils.† The basal conglomerate thus rises in the scale, until from Lower Cambric in southern Wales it has become uppermost Cambric in northwestern Wales.

In Scandinavia the basal Cambric is the Fucoidal sandstone, which appears to represent a reworked continental deposit, as indicated by the presence of the "drei-kanter." This sandstone is probably not of the same age throughout, but represents higher and higher horizons toward the old land, though still holding its place as a basal bed resting directly upon the crystallines.‡ It represents, in other words, a basal clastic of a transgressing sea.

The well known fact that the lowest Cambric deposits of Bohemia are of Middle Cambric age may be cited as another example of the overlap of higher on lower formations in a continually transgressing sea. The basal beds resting directly upon the pre-Cambrics are coarse conglomerates and

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* Hughes: Quart. Jour. Geol. Soc., vol. xxxvi, p. 237; xxxviii, p. 16.

† Professor Hughes, in his second communication, refers the species of Orthis found in the sandstones above the basal conglomerate, which he formerly identified as *O. caraussii*, an Arenig or Tremadoc species, to *O. hicksii*, a Menevian species, making the two types con-specific. On the strength of this, he suggests the possible Menevian age of the basal Cambric beds of Anglesea. Since they are, however, followed without break by typical Arenig strata, and since the species of Orthis found is a typical Tremadoc and Arenig species, even though considered only a variety of the Menevian *O. hicksii*, the reference of these basal beds of Anglesea to the Tremadoc is probably correct.

‡ See Nathorst: Sveriges Geologi, p. 145.

sandstones, the age of which is regarded as that of the *Paradoxides œlandicus* zone—that is, some distance up in the Middle Cambric.

THE BASAL MESOZOIC SERIES

The Central area.—At the beginning of Mesozoic time the North American continent was mostly dry land. Transgression of the sea began in Jurassic time in the Mexico area, and progressed northward and westward, with some oscillations, to southern Colorado and Nebraska, and possibly to southern Dakota, when a period of extended retreat was inaugurated, as recorded in the Dakota sandstone. The record of the advance is embodied in the basal sands of the Comanche series of Texas and the states immediately to the north. The progressive advance of the sea and the resultant rising of the basal sandstone in the scale have been discussed in detail by Hill, who divides the series as follows:*

Washita	Buda limestone. Denison formation. Fort Worth formation. Preston.
Fredericksburg	Edwards formation. Comanche Peak. Walnut.
Trinity	Paluxey. Glen Rose. Travis Peak.

In central Mexico the Comanchean series is composed mainly of limestones which succeed the Upper Jurassic Aucella beds with perfect conformity and continuity of deposition. The Jurassic beds, however, rest unconformably upon the earlier formations, with a basal sand and conglomerate.†

On the tropic of Cancer the basal bed has risen into the base of the Comanchean series, the overlying beds changing progressively through arenaceous and calcareous clays to limestones (Tehuacan limestones). From this point northward to Texas and into Indian Territory the basal bed rises progressively in the series, but with several retreatal movements, which will be referred to more fully below. The general advance, however, is indicated by the change in character and thickness of the formations. Thus, at Austin, Travis Peak beds are over 800 feet thick, and

* R. T. Hill: Twenty-first Ann. Rept. U. S. Geological Survey, pt. 7, p. 115.
† R. T. Hill: Am. Journal of Science, vol. xlv, 1893, p. 311.

begin with basal sands and conglomerates. More than two-thirds of the formation is limestone, and it is succeeded by 600 feet of Glen Rose limestone, the Paluxy being undeveloped as a sandstone. At Twin mountain, in Erath county, Texas, the Glen Rose is a slightly siliceous limestone 5 feet thick, and is inclosed between 115 feet of basal sands and conglomerates and 190 feet of Paluxy sands. At Decatur, Wise county, nearly 100 miles northeast along the strike from the preceding locality, the merest trace of the Glen Rose limestone appears between 200 feet of basal sand and 125 feet of Paluxy. This indicates the uniform thinning northwestward of the formation, largely by disappearance through overlap of the basal members. The age of the basal bed at the localities of the last two sections is clearly Glen Rose, though, as will be shown later, it is nearer the middle than the upper part of the formation.

Along the Texas-Indian Territory line the Trinity beds have disappeared by overlap of the Fredericksburg. Here the basal bed is known as the Antlers sands, and, though spoken of as Trinity by Hill, clearly belongs in the Fredericksburg, since the overlying limestone (the Goodland) is only 25 feet thick, whereas the Comanche Peak and Edwards limestones, which it represents, are 350 feet thick in the Austin region and approximate 700 feet on the Rio Grande. In western Texas, in New Mexico, and in southern Kansas,* the upper Fredericksburg beds are represented only by shore-derived clastics. In southern Kansas they are the plant-bearing Cheyenne sandstone, which rest directly upon the Red beds (Permian) and have a thickness of 65 feet. They are followed by the Kiowa shales, with *Gryphæa corrugata,* which have been found to extend northward into southern Colorado, where they overlie the Morrison formation.† It is not impossible that this horizon or a somewhat higher one will be traced north as far as the Black hills, where a thin limestone band holds the proper position. As will presently appear, only the lowest Washita beds are deposited over this more northern area, the Dakota regression beginning in early Washita, if not actually at the beginning of Washita time, and continuing throughout that epoch.

The West Coast transgression.—Marine Mesozoics are found in various parts of the Pacific coast province of North America. The series begins, as far as we know, with Lower Triassic, though the lowest Triassic (lower Brahminic) has not yet been found. In the Meekoceras beds of the Aspen Mountain, upper Brahmanic and lower Jakutic horizons are known, the former (with Meekoceras, Aspidites, Pseudosageceras, Ophiceras, Proptychites, etcetera) occupying the lower 700 feet and resting upon Carbonic

* **Prosser**: Geological Survey of Kansas, vol. ii, p. 96.
† **Stanton**: Science, n. s., vol. xxii, p. 756.

strata. Higher up in the series occurs *Pseudomonotis pealei,* representing the lower Jakutic stage. Less than 30 miles east, in the Salt River range of Idaho, the *Pseudomonotis pealei* beds rest on limestone with *Productus multistriatus,** thus indicating an eastward overlap.

In the Humboldt mountains of Nevada the Star Peak group of more or less arenaceous limestones, which represents the middle and upper Muschelkalk horizon (Anisic and later), rests on the metamorphic Koipato formation. If no lower horizon is observed in the Star Peak series, an eastward overlap is indicated, since the Meekoceras beds are present in the Inyo mountains of eastern California.

A typical case of overlapping of formations due to the encroachment of the sea exists in the Shasta-Chico series of Oregon, Washington, and British Columbia. The series rests unconformably upon an old land surface composed of more or less metamorphosed strata, ranging in age from Paleozoic to Jurassic and complicated by igneous intrusions. A basal sand or conglomerate is generally present and sometimes seems to grade downward into the rocks of the old land, owing to the apparent slight rearrangement of the disintegration soil formed by the decay of the crystallines. The Lower Shasta or Knoxville beds extend north to the Shasta county line in California, where they are overlapped by the Upper Shasta or Horsetown beds, which extend 125 miles beyond the Knoxville. In this distance the higher beds of the Horsetown progressively overlap the lower ones. Where the Horsetown beds come to an end, the Chico overlap them, resting unconformably on the metamorphics. "The subsidence continued until the sea reached the western base of the Sierra Nevada, near the fortieth parallel, and all or nearly all that part of California north, northwest, and west of Lassen peak, as well as almost the whole of Oregon, was beneath its waters."†

Foreign examples.—The Hils of Germany has long been recognized as a typical basal formation of the transgressing sea of early Neocomian time. This formation consists of a series of clays, with sandstones and conglomerates at the base. They rest, with an hiatus, on various members of the upper Jura from Kimmeridgian to Purbeckian, containing pebbles and worn fossils of these in the basal bed. The age of the basal bed of the Hils varies, ranging from lowest Neocomian to post-Wealden, as shown by the succeeding fossiliferous clays in the various localities. This rise of the basal bed in the column marks the progressive advance of the Neocomian sea over central Europe.

A comparison of the English and Irish Cretacic brings out an interest-

* A. C. Peale: Bull. U. S. Geological and Geographical Survey, vol. v, no. 1, p. 121.
† J. S. Diller: Bull. Geol. Soc. Am., vol. 4, p. 27.

ing correspondence in the lithic character of the sections when read from the base upward; but this correspondence is not parallel in synchronous formations, for the base of the Irish Cretacic is much higher than that of the English. The following sections will illustrate this point:

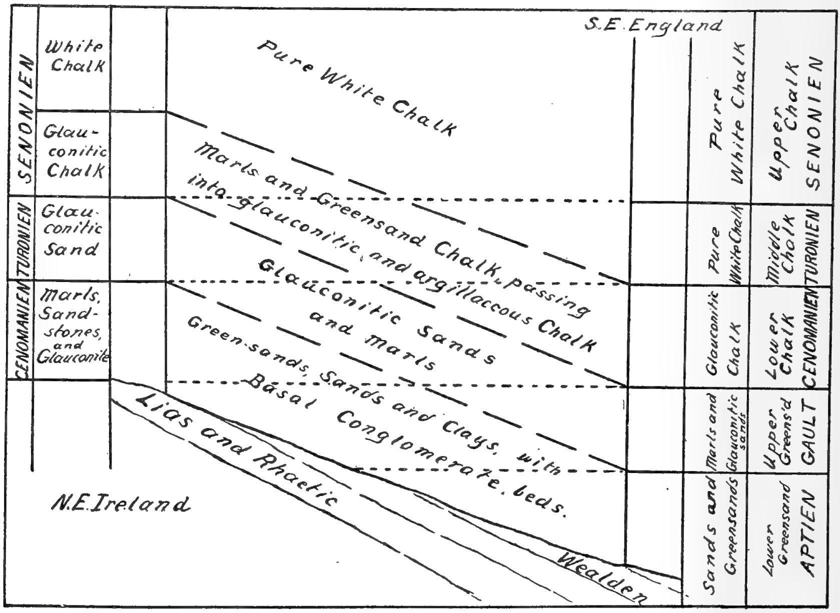

FIGURE 3.—*Diagrammatic Comparison of Irish and English Cretacic.*

In England the basal formation is the lower Greensand (Aptian), which rests on the non-marine Wealden, and is a glauconite and clay formation with basal conglomerates. The corresponding lithic bed in Antrim county, Ireland, is the Cenomanian, which rests on Lias and Rhaetic. The distance is from 300 to 400 miles, in which interval the lower Greensand and Gault have disappeared by overlap, bringing the Cenomanian directly on the old land surface. During the advance, however, the deepening of the English area, and above all the removal of the coast, permitted the deposition of chalk in that region, so that the Cenomanian of England is a chalk, though it still contains Greensand and marl. It is the Lower Chalk of the British geologists. The corresponding lithic bed of Ireland—that is, the Lower Chalk of Ireland, lithically considered—is lower Senonian. Between this and the basal Lower Greensand (Cenomanian of Ireland, Aptian of England) is a glauconitic sand, clay, and marl formation, which in England is the Gault or Upper Greensand (Albian), while in Ireland it is the Turonian, and

in part perhaps Upper Cenomanian. The Turonian, or Middle Chalk of England, is already a pure white chalk, a lithic characteristic attained in Ireland only in the upper Senonian. Thus a regular and progressive advance of the sea from southeast to northwest is indicated, with a corresponding change in lithic character as the sea advanced.

The Nubian sandstone of North Africa and Asia Minor appears to present another case of a lithic formation rising progressively in the time scale. It is the basal sandstone of the Cenomanian and later transgression, and is probably, in part at least, a non-marine deposit reworked by the advancing sea. In mount Lebanon, where this sandstone is 1,600 feet thick, it is succeeded by Turonian strata, while in the Lybian desert Senonian chalk follows it, making the age of the sandstone itself probably Turonian.

Progressive Overlap and the Black Shale Problem

Wherever the relief of the land has been reduced to the condition of a peneplain, the rock surface of the old land becomes mantled with the products of subaerial decay. Prolonged exposure to this process results in the complete disintegration of the mineral constitutents of the rocks, and in the removal, by solution, of all soluble portions. When the rock of the old land surface is a limestone, only the finest residual clay soil will remain behind. The surface of a peneplain is preeminently characterized by obstructed drainage conditions, and this character is the more pronounced the more closely the surface of the peneplain approaches that of an actual plain; hence swampy conditions may be regarded as normal to the peneplain surface; and this brings us to the conclusion that the residual soils of such an area must be highly tinged with the carbon of the decaying vegetation. On old limestone surfaces, the clay becoming thus highly stained with carbon and the residual soil of limestone regions being exceedingly fine in texture, it follows that the resultant deposits from such areas of decomposition will be a fine and uniform grained black clay rock. When the sea encroaches upon such an area of residual soil, the basal formation of the resulting series of deposits will be a black shale, succeeded upward generally by calcareous members, since the shale itself constitutes the finest clastic of shore-derived origin, and any further deposits must be sea-derived—that is, organic or chemical precipitates. It is by no means implied that all black mud deposits originate in this manner. The black muds of the protected lagoons and mud-flat areas of our coasts owe their color and carbonaceous character to the growth and decay of the sea grasses (Zostera, etcetera) and the animals living buried in this mud. The black shales of the Ohio Upper Devonic

probably owe their color to the presence and innumerable minute spores of Rhizocarps, *Protosalvinia huronensis;* and the black muds of partly inclosed basins like that of the Black sea are deep-water deposits, where in the denser lower portions of the water H_2S is generated in great quantity by the activities of sulpho-bacteria.*

If we now set out to interpret the black shale so characteristic of the mid-Paleozoic of the interior region of North America by the light of the facts gained from a study of modern black mud deposits, we are confronted by evidence which points to one or more of the causes cited as probably operative in the production of this deposit. That portions of this shale are due to deposition in a relatively inclosed area, under conditions similar to those existing in the Black sea at the present time, seems probable, since some of these shales in the Portage formation of New York are especially rich in iron sulphide, and are further characterized by the presence of a dwarf fauna, such as is found to be buried in the black muds accumulating in the Black sea today.† But it by no means follows that all the Black shale of eastern United States was deposited in this manner; indeed, the evidence does not admit it even as a tentative assumption. The facts are best set forth by a review of the sections in which the Black shale holds a significant position.

Beginning in the westernmost area of its development on the Mississippi, we find a significant series of sections which may form the basis for the interpretation of the southern shale deposits. The following section was studied by the writer at Louisiana, Missouri, the northwesternmost point of appearance of the so-called Devonian Black shale:

Section at Louisiana, Missouri

	Feet
Louisiana limestone.—Compact limestone or calcilutyte resembling lithographic limestone	50
Immediately below this limestone is a bluish gray arenaceous mud rock, resembling the unweathered Chonopectus sandstone of the Burlington section; when weathered it has all the aspect of that sandstone	1
In one locality the lower part of this lower bed is more argillaceous, containing a fairly rich Kinderhook fauna, with *Spirifer marionensis* and *Productella concentrica* predominating. This shale passes downward without any perceptible break into black fissile rusty shale, resembling in all respects the Genesee shale of New York or the Black shale of Ohio, with which, on this account and on account of its position, it has been identified..............................	4

* Andumow: La Mer Noir.

† See Clarke: Naples Fauna, pt. ii, Mem. 6, N. Y. State Museum. Also F. B. Loomis: Rept. State Pal., 1902.

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Where the one-foot bed below the Louisiana limestone retains its sandy character throughout, the change from it to the underlying black shale is abrupt in color and texture, but there is no indication of discontinuity of deposition; the Black shale and the overlying beds represent one depositional series.

Below the Black shale, and apparently conformable with it, is a brown, much decomposed limestone of arenaceous texture.................. ¾

This passes downward conformably into a fine grained buff siliceous limestone. The thickness of this bed varies in different sections from .... 4 to 10

Underlying this with a somewhat irregular contact is a fossiliferous lime rock with corals and Stromatoporoids indicating its Siluric age.

Although the contact between the brown fine grained limestone and the coarse coral limestone is somewhat irregular, there is no direct evidence of a stratigraphic break here. The irregularity is not more striking than that often found between successive tiers of limestones, where solution along the contact lines will necessarily produce minor irregularities. Moreover, the lower limestone retains its thickness and character in all the sections examined, while the upper brown limestone varies in thickness from place to place. No bedding planes are visible in this brown limestone, and the bedding planes of the overlying shale are apparently conformable with its surface. Nevertheless, it seems as if the line of stratigraphic unconformity (disconformity) is to be sought at the base of or within the Black shale. This deposit is entirely unfossiliferous, but passed upward into a bed with Kinderhook fossils.

At Burlington the Louisiana limestone is underlain by 25 feet of the Chonopectus sandstone, and about 120 feet of a similar but more argillaceous rock, which probably rests upon the Devonic limestones. There is nothing at Louisiana to represent this series, except the 1 foot of rock of the Chonopectus sandstone type and the Black shale. It is true that the Louisiana limestone and the overlying Hannibal and Choteau beds form a greater thickness of rock below the Burlington formation at Louisiana than at Burlington, but it is also true that the fauna of the Louisiana limestone, as far as it is known, is a higher fauna than that of the Chonopectus and lower beds. While the base of the Louisiana limestone may not be and probably is not synchronous in the two localities, yet it seems nevertheless to be the fact that deposition of the Kinderhook began in the Burlington region before it reached the Louisiana region. Thus there appears to have begun a southward transgression of the sea in lower Kinderhook time, and the Black shale of the Louisiana section seems to be the basal bed of the series in that locality.

That this shale is not a deep-water deposit seems evident from its position at the base of a transgressive series of deposits. It seems more in accord with the facts to consider it a slightly reworked residual soil, which had accumulated on the old limestone land surface, probably at the summit of a decomposed mass of limestone, of which the brown bed of variable thickness is the consolidated record.

A section studied by Weller near Springfield, Green county, southwestern Missouri, and one in northern Arkansas has a significance in this connection. The first of these is as follows:

	Feet
Saint Joe limestone—Burlington.	
Kinderhook, consisting of	
Pierson limestone, a fine grained, buff colored limestone with upper Choteau fauna	3 to 10
North View sandstone, lithically identical with the Vermicular or Hannibal sandstone of the Mississippi section, but having a fauna similar to that of the upper yellow sandstone of Burlington	10 to 90
Phelps sandstone, carrying numerous black phosphatic nodules and fragments of worn fish teeth, identified as Devonic	0 to 4
Sac limestone, a hard bluish gray compact limestone, with a Choteau fauna	1 to 18
Eureka (Noel) black shale, with Kinderhook fossils	0 to 4
Disconformity.	
Magnesian limestone (Ordovicic).	

Weller correlates on faunal basis the Sac limestone with the upper yellow sandstone overlying the Louisiana limestone in the Burlington section, or the Hannibal sandstone and Choteau limestone of the northeastern Missouri sections. Accepting this correlation as the true one, we find that the overlap southward has brought the black basal shale (Eureka or Noel) into the upper part of the Kinderhook formation. This is borne out by the fossils of the Black shale, which are later than the Chonopectus horizon. It must be remembered, however, that the northeast Missouri sections are on the flanks of the Ozark uplift, and that the transgression there may have been a local one. If that is the case the total southward overlap is actually greater, since in the absence of the Ozark uplift the actual base of the section would be lower than it is in northeastern Missouri, and hence the rise of the basal black shale would be from a lower position than now in the northeast to the indicated position in the southwest of the state.

In northern Arkansas the Eureka, or Noel black shale, represents the same facies of sedimentation as in southwestern Missouri, and, as in that section, contains fossils showing its age to be younger than that of the

Chonopectus sandstone of Burlington. It rests on the eroded lower Magnesian limestone (Ordovicic) and varies in thickness from a few inches to 70 feet. It is not always black, but sometimes greenish or yellowish, and has thin limy members toward the top. It is immediately succeeded by the Saint Joe limestone (Burlington), into which it is often seen to grade. The connection between the two is an intimate one and represents continuous deposition. This fixes the date of the Eureka (Noel) shales of Arkansas as latest Kinderhook and shows an overlap from the base of the Choteau to the base of the Burlington, during the transgression of the Kinderhook sea from southern Missouri to northern Arkansas. Here the basal black shale takes the place of the basal sandstone of the basal Palèozoic sections; but, like that sandstone, this basal shale rises in the scale with the progress of the transgression. It is hardly questionable that the Black shale represents the reworked residual soil of the old land of Ordovicic limestones in the Missouri-Arkansas section. The shale rests unconformably on various members of the Lower Paleozoic limestones, and in each case derives its mineral character from the bed underlying. According to Ulrich, the shale is found resting only on the Key sandstone (Saint Peter), or the magnesian limestone of earlier age (Yellville formation). Where the Black shale is not developed, another formation, the Sylamore, often lies between the Saint Joe and the underlying Ordovicics (Polk Bayou limestone). The Sylamore formation consists of a shale with a maximum thickness of 15 feet, succeeded by a sandstone of coarse rounded quartz grains containing phosphate nodules. The shale is sometimes black and then resembles the Noel shale, with which it is generally correlated. Ulrich, however, insists on the Devonic age of this rock, on the strength of some fragmentary fish remains (a mandible doubtfully referred to Dynichthys) which indicate that age, and of some invertebrate fossils "which tend to corroborate this view." The fossils recorded are "a small Lingula that may be the same as *L. spatulata* of the Genesee shale of New York, and some conodonts." If this view is correct, there is a pronounced hiatus at the top of the sandstone, for the whole Kinderhook formation is wanting. The phosphatic pebbles of the Sylamore are sparingly represented in the basal portion of the Saint Joe, which is interpreted by Adams and Ulrich as the result of reworking. Ulrich states that "the Sylamorė formation impresses one as the waste of a near-by shore, and thus agrees, not only in its faunal and physical character, but also in its origin, with the Chattanooga formation as developed in middle Tennessee."* The Noel shale, on the other hand, is correlated

* George Adams and E. O. Ulrich: Professional paper no. 24, U. S. Geological Survey.

by Ulrich with the base of the Tullahoma formation of middle Tennessee. That the hiatus recorded or believed to exist between the Sylamore and Saint Joe is equivalent to the whole Kinderhook may be doubted. The evidence on which to base the reference of the Sylamore to the Devonic is altogether too meager; it is far more likely that this formation represents a basal bed of Kinderhook age, possibly in part continental, and that it is in general equivalent to the Noel shale, as held by earlier writers.

Whatever the age of the Sylamore, the relationship of the Black shale (Eureka or Noel) to the overlying and underlying formations is clear. It represents a basal bed of an advancing sea, and progressively rises in the scale southward from middle Kinderhook to uppermost Kinderhook or lowest Burlington. That this basal bed is such a fine grained rock can only be explained by the assumption that the land was very low, and that the residual soil covering it was clay mixed with much carbonaceous material. In other words, the Noel shale can only represent the re-

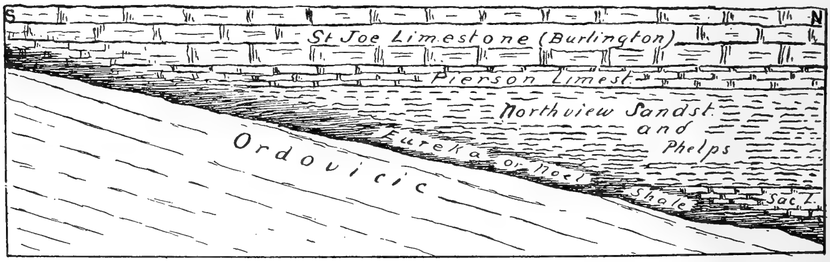

FIGURE 4.—*Diagrammatic View of the Relationship of the Black Shale of southern Missouri and northern Arkansas to the overlying Formations.*

worked residual soil of an old peneplain surface which was slowly submerged beneath the advancing Mississippian sea. Taken in connection with the position of the Black shale at the base of the Louisiana limestone in northeastern Missouri, we see that the transgression went on through the entire Kinderhook.

There seems to be no valid reason for considering that the Black shale of northeastern Missouri had a different origin from that of southwestern Missouri; and if the Noel shale represents the basal bed of a transgressing sea in southern Missouri and northern Arkansas, there is no reason for regarding the Louisiana Black shale as having a different meaning. A significant fact in this connection is the similarity in the general lithic character of the section in northeastern and southwestern Missouri. In the northwestern section the shale is succeeded by the compact Louisiana limestone; this by the Hannibal sandstone or vermic-

ular sandrock, and this by the Choteau limestone. In the southwestern section the Black shale is also succeeded by a compact limestone (the Sac), followed by a vermicular sandstone (the North View, identical in character with the Hannibal, and formerly identified with it by the Missouri geologists) ; and finally by a fine grained buff limestone (Pierson limestone) representing the Choteau of the northeastern section. In actual age the Sac, North View, and Pierson of the southern section are equivalent to the Hannibal and Choteau of the northern one. This similarity of lithic succession strengthens the case and makes it practically certain that we have in the Black shale of the Mississippi valley a basal bed of a transgressing sea, and that the age of this basal bed, as in the case of basal sandstones, varies from place to place, rising southward in the series. Compare figure 4.*

With this demonstrated example before us, we may next consider the Black shale of the southern Appalachians, which is universally regarded as of Devonic age in all of its exposures. Ulrich has recently restated his convictions in this matter by proposing to apply the name Ohio shale to this formation wherever found. Even if this shale represented only Devonic beds in its different outcrops, the fact remains, and is recognized by Ulrich, that it does not represent the same portion of the Ohio series in all its exposures. That part generally known as the Chattanooga shale is regarded by Ulrich as representing the upper part of the shale in Ohio, and to call this small portion by the name of the whole is at least a questionable proceeding.

The Devonic age of the Chattanooga shale may, however, be seriously doubted. The establishment of this age is not based upon fossils; for those found—a few Lingulas, doubtfully referred to *L. spatulata* of the Genesee, and some Conodonts—are wholly inconclusive. Ulrich himself says:

"Although there is little besides stratigraphic position and lithologic characters on which to base the reference of this black shale to the Ohio formation, it is so referred with the utmost confidence. In every feature this [Hardin County] shale is practically identical with many of nearly a hundred exposures of this formation examined by the writer in Kentucky, Tennessee, and Ohio. From lake Erie southward to northern Georgia and westward to this district the Ohio shale is remarkably constant in its lithologic characters. Despite this constancy this formation has received a number of names. The name Ohio shale, proposed by Andrews, the oldest of the geographic names applied to this formation, is here adopted."†

* Compare this similarity of succession with that found in the chalk of England and Ireland, cited above.

† Professional paper no. 36, p. 25.

According to this reasoning, based wholly on lithic characters, the Marcellus and Genesee shales of western New York should be regarded as synchronous, and both should be identified with the Rhinestreet or any other of the black shales of that region; for "in every [lithic] feature this . . . [Marcellus] shale is practically identical with many of nearly a hundred exposures . . . [of black shales of varying horizons] examined by the writer."

The Chattanooga shale in the region of the Columbia quadrangle in central Tennessee is described as having generally at the base a thin bed consisting largely of calcium phosphate and forming the source of the Tennessee black phosphate. In many cases these phosphate nodules surround minute coiled shells derived from the underlying Ordovicic limestones. This phosphate bed passes by gradation laterally into a bed of coarse sandstone or conglomerate containing varying amounts of phosphate and much water-worn material, together with some unidentified fish bones. Sometimes, toward the southwest, the phosphate is replaced by a fine grained gray or black sandstone, with a maximum thickness of 12 feet in Hardin county (Hardin sandstone). Where the Chattanooga formation rests on the Clifton or on the Fernvale formation (limestones), it is always a black shale at the base. The Maury green shale is generally found at the top of the Chattanooga formation. It varies from a few inches to 4 or 5 feet in thickness in central Tennessee, though it does not exceed 2 feet in the Columbia quadrangle. It contains lime phosphate and Greensand grains, which are the cause of the color.

"Rarely, as in the upper part of East fork of South Harpeth creek, the green shale is absent or not distinguishable, and in these cases the black shale *seems to pass very gradually into the overlaying green shale* * which constitutes the base of the full Tullahoma section."†

The Tullahoma formation of shales passing up into cherty limestones is from 200 to 500 feet thick and is believed by Ulrich to represent the whole of the Waverly of Ohio; but it is probably more correctly regarded as representing only the upper part of that formation, which in southern Ohio is considerably over 600 feet thick.‡ There is no recorded evidence from fossils which would establish the equivalency of the Tullahoma to the whole of the Waverly, since fossils are extremely scarce in the Tullahoma of Tennessee. Apparently the correlation is based on position alone, as the formation succeeds the black shale, which is on *a*

* The italics are the present writer's.
† Columbia folio, p. 3.
‡ Harrick: Bull. Geol. Soc. Am., vol. 2, p. 40.

priori grounds considered by Ulrich to be Devonic, and is followed by the Saint Louis limestone series. Of course if we regard the black shale as Devonic, then the fact that it grades up into the Tullahoma indicates that the base of the Tullahoma is basal Mississippian; but until more convincing evidence is brought forth of the Devonic age of the black shale and the basal Mississippian age of the Tullahoma, the more normal interpretation is that both are above the base of the Mississippian—approximately of upper Kinderhook or lower Osage age.

Foerste has recorded the frequent presence of sandy and earthy layers at the base of the Black shale in the most eastern exposures on the Cumberland river, these layers being phosphatic.* This basal portion usually varies between 2 and 3 feet, but thicknesses of even 6 feet are found locally. Sometimes it is replaced wholly or in part by greenish more clayey layers. In this sandy layer occur weathered out fossils of the underlying Ordovicic rocks. Foerste has also recorded traces of Chonetes and other fossils in the fine grained rock immediately above the Black shale, south of Rockdale.† He considers that the beds containing these fossils may be of Waverly age. In regard to the contact between the black shale and the Waverly, he says:

"In the gulley southeast of the Oliver Williams house the base of the section consists of a dark, sandy, partly conglomeratic rock 18 inches thick. Both the Black shale and the phosphate rock are absent. Immediately above the conglomeratic rock occur 11 inches of light green clayey rock containing purple brown phosphatic material, both in the form of small irregular particles and of nodules. Above this are found 8 inches of crinoidal greenish rock, with fish teeth. At the 'Big hill,' immediately westward, on the road to Waynesboro, the entire Black shale section is absent.

"The purple brown phosphatic material found immediately above the conglomeratic, sandy rock at the Oliver Williams locality resembles the material forming the phosphatic nodules at the top of the Black Shale section in most parts of Tennessee and Kentucky. The fish teeth appear to belong to the same formation as the bed from which the phosphatic material was obtained. The greenish clay material, however, belongs to the Waverly horizon, so that the base of the Waverly appears to contain material derived from the eroded top of the Black Shale bed. The crinoidal material is unquestionably of Waverly age. The fine grained but not fissile rock in the old Sawmill hollow may also be of Waverly age, since species of Chonetes of the same general form are rather common at the base of the Waverly section in the northern part of Giles county. The dark color of the rock may be due to the carbonaceous material received from the denuded Black shale of this area, while the more sandy character may be due to material washed in from some other source by the Waverly sea. The gradual passage of the black rock upward into the

* A. F. Foerste: Silurian and Devonian limestones of Tennessee and Kentucky. Bull. Geol. Soc. Am., vol. 12, 1901, p. 427.

† Loc. cit., p. 428.

greenish rock, as already described, is also favorable to the view that the black rock, without good fissile cleavage, may be of Waverly origin. In case these observations are correct, the absence of the Black shale at the 'Big hill' may be due, not to original lack of deposition, but to subsequent erosion."

Foerste raises the question whether the observed thinning of the Black shale toward the Cincinnati dome may not be due to a "marked development of the southern end of the Cincinnati anticline at the time of the deposition of the Black shale and the base of the Waverly."* In other words, he believes that less shale was deposited on the rising portions of the dome. It may also be interpreted as resulting from the washing of the residual soil from the higher into the lower places; and this readily accounts for the absence of the shale in many places not as due to erosion prior to the deposition of the Waverly and the occurrence of a disconformity, which such a fact would imply, but as the result of the washing of the original soil from the higher parts, on the encroachment of the lower Mississippian sea. This explanation is further suggested by the fact that within short distances in all directions the shale reappears. In general the coarseness of the material increases from the northeast to the southwest. Regarding the physical conditions under which the shale was deposited, Foerste says:†

"In the case of the Black shale, the evidence of land conditions or of fresh-water conditions is more favorable. At many points through its entire extent it has retained remains of land plants. Its strongly carbonaceous character, which gives rise to the black color of the shales, does not necessarily indicate the presence of land plants, although the presumptive evidence is in favor of this view. At various localities the remains of animals have been preserved in this shale. . . .

"The base of the Black shale is often decidedly earthy and is often also phosphatic. It is well known that the base of the Black shale is in many parts of southern Tennessee sufficiently phosphatic to be worked as a phosphate rock. One of the theories of the accumulation of the phosphatic material at this horizon is that it was derived from the phosphatic material included in the shells of the underlying Silurian and Ordovician rocks; that it is an accumulation in one sense of residual material.

"This sandy base of the Black shale occasionally incloses fossils derived from the underlying formations. The sandy material itself is probably of residual origin. It may represent a residual soil, but the evidence is again inconclusive.

"The fissile black shale is composed of particles so light that they could have easily been blown by the wind. The remarkably fine grained character of the fissile shales, the entire absence of coarser material except at their base, and their remarkably wide geographical distribution suggest that they may possibly consist of wind-blown particles, derived perhaps from many strata, from

* Loc. cit., p. 429.
† Loc. cit., pp. 430, 431.

points far distant from one another. The absence of coarse detrital material suggests that the region of deposition was practically flat. The preservation of fragments of land plants indicates that it was probably a region of marshes. It may be imagined that the same particles traveled in many directions before finding a final lodgment. Marshes at one point may have dried up, and the material accumulated in it may have again turned into dust, thus permitting the frequent shifting by the wind of the materials which now form the shale."

Safford records the occurrence of thin seams of bituminous matter from an eighth of an inch to an inch in thickness. "The bitumen of these shales is hardly an asphaltum, being *generally,* perhaps, more like the bitumen of cannel coal."* Petroleum also oozes from the shale in a few places and can be readily distilled from it.

In Wayne county, south central Tennessee, the following section was made by Safford at T. A. White's mill, on Buffalo river, a few miles below the mouth of Green river:

	Feet
(4) A thin bed of *gravel* (water-worn pebbles) on top, with some loose, angular chert. The gravel is found at the top of all the high ridges in this region. Specimens of *Lithostrotion canadense* (not water-worn) are also found loose on the surface.	
(3) *Siliceous group:*	
Rocks concealed, surface covered with small, angular, cherty masses, to top of ridge	190
Bluish shale, with layers of chert	15
Bluish shale	24
In all	238
(2) *Black Shale group:*	
(*c*) Layer of kidneys	½
(*b*) Black shale	2
(*a*) Sandstons, at top thin bedded, surfaces abounding in Lingulæ	9
In all	11½
(1) *Meniscus limestone* (Niagara):	
Gray, mostly crinoidal limestone; contains the characteristic *Haplocrinus hemisphericus* immediately below the sandstone; thickness down to the water	67

In eastern Tennessee (McMinnville folio) the Chattanooga Black shale rests on the Chickamauga limestone (Ordovicic) and has a thickness of from 10 to 30 feet. It consists mainly of highly carbonaceous non-fissile shale. The upper stratum, about 2 feet in thickness, is generally bluish green, somewhat sandy, and contains a layer of small phosphatic concretions an inch or less in diameter. "It seems probable that this upper greenish layer of shale represents an ancient ash bed, the material of which was ejected from a volcano and transported a long

* J. M. Safford: Geology of Tennessee, 1867, p. 334.

distance from its source, partly by winds and afterward by currents, when it had fallen on the surface of the sea which then covered this region."* Small concretions of iron pyrites occur in the shale.

The shale is here overlain by from 150 to 225 feet of the Fort Payne chert. This begins usually with heavy beds of chert at the base, with only a little limestone or shale, passing upward gradually into purer limestone and "without abrupt transition into the Bangor limestone above." This series is from 700 to 800 feet thick. The Fort Payne chert is very fossiliferous, and is the "siliceous group" of Safford, which he divided into a lower, or Protean (Lauderdale, McCalley), and upper, or Lithostrotion (Tuscumbia, McCalley). Ulrich makes the Tullahoma of central Tennessee and the Fort Payne of eastern Tennessee equivalent, and correlates both with the Kinderhook and Osage of the Mississippi valley. There is here an inconsistency, for the upper part of the Fort Payne (Tuscumbia) is clearly of lower Saint Louis age, as shown by the abundance of *Lithostrotion canadense* (=*L. mamillare*).

Stevenson considers that the upper part of the Fort Payne is unquestionably Tuscumbia, but he also says:†

"It is difficult to determine, by means of available observations, whether or not the Fort Payne of the extreme southeasterly areas embraces any Tuscumbia. For the most part the features are those of the Lauderdale (Logan), there being an almost total absence of limestone in the upper part; but in Calhoun county of Alabama, very near the extreme southeast exposure, one finds the Tuscumbia clearly present. One may conjecture that as the Lauderdale is practically without limestone nearer the shore line the Tuscumbia would undergo the same change, so that the thin Fort Payne on the border would represent both. This is in accordance with the conditions in this region, as each of the Mississippian formations apparently overlaps its predecessor."

Nor is the Protean, or Lauderdale, the equivalent of the whole Tullahoma (as defined by Ulrich—that is, =Kinderhook-Osage); for, according to Safford:‡

"This lower, or Protean, member of the Siliceous group, is, in general, equivalent to the divisions of the Lower Carboniferous limestone lying below the Saint Louis limestone. It is, perhaps, more especially the equivalent of the Keokuk limestone; it contains, however, some Burlington forms."

He lists the following species from this member: §

Spirifer imbrex Hall. "Occurs *immediately* above the Black shale below Huggins's mill, near Manchester, in Coffee county, associated with *Productus*

* Hayes: McMinnville folio.

† J. J. Stevenson: Lower Carboniferous of the Appalachian basin. Bull. Geol. Soc. Am., vol. 14, 1903, pp. 14-96.

‡ Safford: Loc. cit., p. 342.

§ Ibid.: Loc. cit., pp. 342, 343.

semireticulatus; also in the same horizon at White's Creek Springs, and near Colonel Robinson's, on the Middle fork of Cold water, in Lincoln county."

Spirifer subequalis? Hall.
Spirifer tenuicostatus Hall?
Spirifer suborbicularis Hall.
Spirifer subcuspidatus Hall [*Syringothysis texta*].
Spirifer lineatus Martin.
Orthis [*Rhipidomella*] *michelini* L'Eveille.
Platyceras equilatera? Hall.
Granatocrinus granulatus Roemer.
Agaricocrinus americanus Roemer.
Actinocrinus conicos Cassedy and Lyon.
Actinocrinus nashvillæ Troost.
Actinocrinus (*Batocrinus*) *magnificus* Cassedy and Lyon.
Actinocrinus (*Dorycrinus*) *gouldi* Hall.
Cyathocrinus stellatus Hall.
Forbesiocrinus meeki Hall.
Forbesiocrinus saffordi Hall.
Ichthiocrinis tiaræformis Troost.

Commenting on these, he says:

"Most of the above species occurring out of Tennessee are Keokuk forms. *Spirifer imbrex* and *Orthis michelini* are found in the Burlington limestone; *Spirifer subæqualis* and *S. tenuicostatus* are Warsaw forms, and the latter also Keokuk."*

The thickness of the Lauderdale in its typical development in Tennessee is 250 to 300 feet, but it decreases southward, undoubtedly through the failure of the lower beds. The Tuscumbia, the equivalent of the Saint Louis limestone of Missouri geologists, has a maximum thickness of 250 feet. Safford holds that the lower member (Lauderdale) thins away southward. He says:

"In the southern part of the state, at certain points, the member is cherty, crinoidal limestone, resembling the Lithostrotion bed above. In fact, going southward, the lower member becomes thin, and below Huntsville on the anticlinals of Alabama, the two members, in my opinion, become one bed, characterized throughout by *Lithostrotion canadense*."†

In a foot-note he adds:

"A little below Gadsden, in Alabama, I have seen a number of specimens of this coral [*L. canadense*] in an outcrop of the Siliceous chert, very near the Black shale."

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* Ibid.: Loc. cit., p. 343.
† Ibid.: Loc. cit., p. 340.

Except where an erosion interval is responsible for the thinning away of the Fort Payne or Siliceous group, we must assume that the thinning is due to the failure of the basal members which are overlapped by the higher members. All the descriptions indicate a passage of the Fort Payne into the overlying lower Bangor, or its equivalent, the Floyd shale. Where the Fort Payne is represented by less than 100 feet, this thickness must represent the upper, or Tuscumbia, portion, unless an erosion interval has removed a part of the upper portion before the deposition of the Bangor. As already noted, however, such a disconformity has not been recognized. It may, of course, be true that the Fort Payne, recognized by its lithic character, has not the same position everywhere, and that the lower Bangor of the southeast may represent a part of the Tuscumbia farther west. However that may be—and the point can only be settled by a careful examination of the sections—the fact remains that the Lithostrotion bed in many places is close to the Black shale, and in fact lies directly upon it.

In the McMinnville quadrangle the base of the Fort Payne, which varies from 150 to 225 feet, is probably of Keokuk age.

Southeastward, in the Sequatchee valley, the Chattanooga (12 to 25 feet thick) is succeeded by only from 60 to 80 feet of the cherty Fort Payne, which here represents the highest part of the group, or the Saint Louis horizon, unless there is an erosion break at the top or the top is here lower than elsewhere. It is described as passing upward into the Bangor limestone.*

In the type region, in the Tennessee valley, near Chattanooga, Tennessee, the shale is from 10 to 25 feet thick, while the overlying Fort Payne is reduced to from 60 to 150 feet in the western region and from 50 to 75 feet in the southeastern region. As before, if the section here is complete, the Fort Payne can only represent the Saint Louis horizon. Above it comes the Floyd shale in the eastern, nearer shore section, and limestones in the more western, offshore district. The Floyd shale of the eastern section is later replaced by limestone of the type of the Bangor, but the equivalent of only the upper Bangor of the sections farther west, the Floyd shale itself being the equivalent of the lower Bangor.

A remarkable condition is found in the Chilowee mountain area. Here the Chattanooga shale ranges from 6 to 30 feet in thickness, and is succeeded by the Grainger shale. It "comprises flaggy sandstones, sandy shales and sandstones, with white sandstone and red and brown sandy shales at the top; and this series is present throughout."† The lower

* Sewanee folio.

† Loudon and Knoxville folios.

sandy beds are fossiliferous, containing fenestellæ, linguæ, and brachiopods. The age of these shales in this section has not been determined. They are, however, classed as Devonic, together with the Black shale, though from what is known of these deposits farther northeast their age is, at least in part, lower Mississippian. The thickness of the formation is 1,100 feet. It is succeeded by the Newman limestone, which includes 100 feet of massive blue limestone at the base, followed by 500 feet or more of gray calcareous shale and shaly limestone. The basal portion is highly fossiliferous, containing crinoids, corals, and brachiopods. It is succeeded by the Lee conglomerate (Pottsville). Northwest of Chilhowee, some 30 to 35 miles, in the Walden ridge, the Newman limestone, 700 feet thick, rests directly on the Chattanooga shale, which is here 80 feet thick and rests disconformably on the Rockwood. The Newman is here mainly a marine limestone, with chert nodules in the base. Its age is Saint Louis and it is succeeded by the Lee conglomerate. Northeastward, in the Clinch mountains of northeast Tennessee and southwest Virginia, the Grainger shale and Black shale are both well developed.* At Big Stone Gap, Virginia, the Black shale, which is at least 500 feet thick, rests on sandstones of late Helderbergian age.† The Black shale contains an abundance of *Lingula ligea* and *Schizobolus concentricus,* both late Devonic species. The age of the base of the shale in this place is therefore Upper Devonic. Professor Williams studied the section at Big Stone Gap in great detail, and he found "that the following arenaceous shales and sandstones began as very thin intercalated sheets, thin as paper at first, far down in what, to the casual observer, appeared to be pure black shale."‡

Farther eastward, at Big Moccasin Gap, Virginia, the following section was made by Williams and Kindle:§

	Feet
7. Limestone and shale (Mississippian)	
6. Soft yellowish clay and crumbling sandstone	100
5. Hard, drab colored sandy shale and sandstone	40
4. Conglomerate bed near top of 3 feet.. 3. Hard, bluish gray to drab sandy shale	60
2. Black shale, varying to gray, and much crushed and folded	150
1. Tough quartzitic fine grained sandstone	75

"In the Estillville folio, 2 is called the Chattanooga Black shale, and 3 to 6 are assigned to the Grainger shale. The lowest fauna obtained from the section is from the lower part of 3, about 20 feet above the Black shale."

* Estelville folio.
† Williams and Kindle: Bull. U. S. Geological Survey, no. 244, p. 28.
‡ Williams: Southern Devonian formations. Am. Jour. Sci., vol. iii, 1897, p. 389.
§ Williams and Kindle: Loc. cit., p. 30.

The following species are listed:*

[*c*, common; *r*, rare.]

Zaphrentis sp. (*r*).	*P.* cf. *wortheni* (*c*).
Crinoid stems (*c*).	*P.* sp. (*r*).
Fenestella sp. (*r*).	*Camarotœchia* sp. (*r*).
Lingula gannensis (*r*).	*Spirifer* cf. *marionensis* (*c*).
Orbiculoidea sp. (*c*).	*Reticularia pseudolineata* (*c*).
Chonetes sp. (*r*).	*Syringothyris carteri* (*r*).
Productus cora var. (*r*).	*Athyris lamellosa* (*c*).
P. cf. *semireticulatus* (*r*).	*Conularia* sp. (*r*).

Forty feet higher another rich Kinderhook, or early Burlington fauna was found, including *Spiriferina* cf. *solidirostris, Palæoneilo perplana, P. sulcatina, Nuculana spatulata, Pleurotomaria stulta, Prolecanites greeni,* Phæthonides, and others. Thirty to forty feet higher still the fauna is still more characteristically lower Mississippian, for such species as *Lingulodiscina newberryi, Spirifer keokuk, Sphenotes flavius, Palæoneilo bedfordensis,* and *Conularia newberryi* occur, most of them common, besides many others not determined specifically.†

The sandstone number 6 of the section afforded *Productus cora* and *Camarotechia contracta,* both common.

At Hicksville, Bland county, Virginia (Pocahontas folio), the Black shale, here called Romney, has an estimated thickness of from 400 to 600 feet and rests upon sandstone with an Oriskany fauna. It contains *Schizobolus truncatus, Palæoneilo brevis,* and Goniatites, which occur 100 feet above the top of the Black shale; and, higher still, the Kimberling shales and sandstones have yielded a rich Chemung fauna. The Black shale has here descended in the scale and apparently represents Portage time. Still farther northeast, at White Sulphur Springs, West Virginia, the Black shale, resting on Oriskany sandstone, is succeeded by sandy and green shales with a *Buchiola speciosa* or Naples (Portage) fauna, followed, 300 feet above the Black shale, by a Chemung fauna.

At Covington, Alleghany county, Virginia, 20 miles from the last section, and at Hot Springs, Bath county, Virginia, the Black shales carry in the lower part Marcellus species, though associated with species of late Devonic time. Williams holds that the Black shales began to be deposited here while the Onondaga fauna still continued in the more central area. The evidence for this seems hardly conclusive. At Covington, Virginia, the Black shale is underlain by a greenish shale with *Schizophoria striatula, Atrypa spinosa, Ambocœlia umbonata,* and

* Ibid.: Loc. cit., p. 30.
† Ibid.: Loc. cit., p. 31.

Phacops rana. This is a Hamilton or later fauna, and although the fauna of the Black shale includes *Leiorhynchus limitare* and *Agoniatites vanuxemi,* both of them typical Marcellus species, the fauna as a whole is certainly Upper Devonic (Naples-Portage), as stated by Williams. The same thing may be said of the Hot Springs section; for here the *Buchiola speciosa* fauna is abundant only 70 feet above the Black shale, 60 feet of the interval immediately below the shales with this fauna being concealed. In the 9 feet of white or cream colored shale immediately over the Black shale occur *Orbiculoidea doria, Bellerophon leda,* and *Styliolina fissurella,* besides others unidentified specifically. The Black shale itself contains *Orbiculoidea doria, Styliolina fissurella,* and questionably identified *Chonetes* cf. *coronatus,* and *Anoplotheca* cf. *acutiplicata.* The evidence adduced, then, points to an early Upper Devonic age of the Black shales at Hot Springs, rather than a lower Middle Devonic, as advocated by Williams. The Black shale is 10 feet thick and rests upon Oriskany (?) sandstone.

In Allegany county, Maryland, the Black shale forms the base of the Romney formation, which has a thickness of about 1,600 feet. Here the shale is clearly of the age of the Marcellus of New York, and in part it also represents the Onondaga. This portion of the formation rests upon the Oriskany and has a thickness of about 500 feet. The upper 1,100 feet of the Romney contains a typical Hamilton fauna.* Eastward from this, in Washington county, the Hamilton division of the Romney overlaps the Marcellus, which is only sparingly represented.†

We have here clear evidence of a continued southwestward progression of the encroaching sea, and a corresponding progressive overlap of the higher formations southward. In all cases a basal black shale occurs, rising in the scale from Marcellus or lower in the north to uppermost Devonic and, as indicated in Big Moccasin Gap, to Lower Carbonic.

At Irvine, Kentucky, the Black shale again lies high up in the series, for here it has intercalated in its upper part calcareous and ferruginous concretionary sheets which carry undoubted Lower Carbonic fossils. These occur in the sections before the Black shale loses its characteristic expression.‡

In the London quadrangle of central Kentucky the Chattanooga shale rests on Devonic limestones with an erosion interval. It has a thickness of 150 feet, is very black and bituminous. It is succeeded upward by a light blue clay shale and argillaceous sandstone, the shale abounding in light blue or drab ironstone concretions. Many siliceous concretions

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* Prosser: Journal of Geology, vol. xii, p. 361.
† Ibid.: Loc. cit., p. 362.
‡ Williams: Amer. Jour. Sci., vol. iii, 1897, p. 398.

occur. Upward it passes into sandy shale and argillaceous sandstone. The thickness averages 350 feet, and it is succeeded by the Newman limestone, 100 to 250 feet thick, and the Pennington shale, which is occasionally absent. Above this is a great erosion break, followed by Pennsylvanian sandstone. The shale above the Black shale is referred to the Waverly, of which it probably constitutes the upper portion only. As at Irvine, the transition from the Black shale to the overlying beds is probably a gradual one.

Taken together with the section at Chilhowee mountain, Tennessee, where the Grainger shale, 1,100 feet thick, separates the Black shale from the Newman limestone—and with the section in Walden ridge, 30 miles northwest, where the Newman limestone rests directly on the Black shale—it becomes apparent that a ridge of land extended southeastward, approximately along what is now the Walden ridge of Ten-

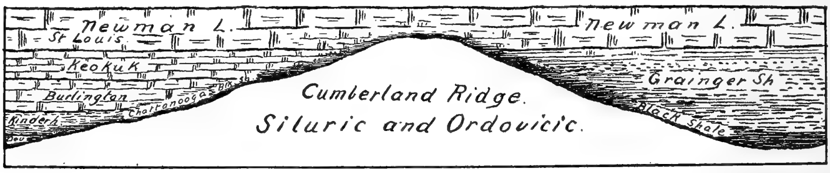

FIGURE 5.—*Diagram of Cumberland Ridge showing Relationship of interior Sea to oceanic Channel.*

nessee and the Cumberland mountains and westward in Kentucky, separating the interior basin from a channel to the east of this ridge. Whether this channel was in direct communication with the Atlantic to the south or whether it represented an encroaching arm of the sea from the north is a matter for further investigation. The sections given so far indicate that the latter condition obtained, since the formations overlap progressively southward along this channel. West of this barrier the Mississippian sea was slowly encroaching southward and eastward, as shown by the overlapping beds, until in Saint Louis time the barrier became submerged and the Newman limestone was spread uniformly over the whole area. The relationship of the interior sea to this channel and to the formations accumulating in each is shown in the accompanying diagram.

In the region about Rome, Georgia,* the Frog Mountain sandstone rests unconformably on the Rockmart and other formations in the southwest area and in the adjoining Fort Payne quadrangle. "It consists chiefly of white quartzitic sandstone and yellow porous sandstone, the latter prob-

* Rome folio.

ably containing feldspar. It also contains some sandy shales." The age is Oriskany, as shown by the occurrence of some poorly preserved fossils. It has a thickness of 1,200 feet and over. On the north side of the Coosa valley the Armuchee chert replaces the sandstone with a thickness of 50 feet. The chert is bedded and contains fossils similar to those of the Frog Mountain sandstone, of which it probably represents an offshore deposit.

There is a marked time break and erosion interval above these formations, followed by the Chattanooga Black shale. This consists of two divisions. The lower, with a maximum thickness of 40 feet, but decreasing to 1 or 2 inches in places, is jet black and rests on the Armuchee chert or directly on the Rockmart sandstone. The upper member consists of blue or greenish clay shales, usually with phosphatic concretions, which are generally perfectly round, when small; but when sometimes they reach a diameter of a foot or more, they are oval. The green color of the formation is due to the presence of glauconite. This upper member varies from 1 to 3 feet in thickness and apparently represents the Maury shale of central Tennessee. The Chattanooga is succeeded by the Fort Payne, from 20 to 200 feet thick, and this by the Floyd shale, 2,000 feet or more in thickness, or by the Bangor limestone.

At the base of the Black shale opposite Rome, Georgia, a few fossils have been found suggestive of Hamilton age, but the evidence is scarcely conclusive.*

Summing up the facts so far determined, it becomes apparent that there is in the interior area a progressive overlapping of the Mississippian formations southward and eastward, beginning in Kinderhook time and continuing, practically without interruption, throughout that epoch; for Mississippian strata are wanting in central Texas, where the mid-Carbonic strata rest directly and unconformably on earlier Paleozoics. A southward transgression also took place in the area east of the old Cumberland land ridge, which was eventually submerged in later Saint Louis time. Whether or not land conditions existed throughout the southern parts of the Gulf states is not determinable from the data at hand.

Nearly everywhere resting directly on the surface of the slowly subsiding old land lies a bed of highly carbonaceous shale. In its basal portion, in many localities, it contains fossils weathered out of the underlying Ordovicic strata. Sometimes it is replaced by a sandstone or conglomerate; sometimes it carries worn fish bones; in many places, too, it carries remains of land plants. Several observers have been struck

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* Schuchert: American Geologist, vol. xxxii, p. 152.

by the resemblance of this basal shale to an old residual soil, though Hayes believes that in some areas the old-land surface was scoured by ocean currents before the deposition of the shale.† Where detailed observation has been made the shale is said to pass upward into the overlying beds. Though Ulrich has marked an unconformity at the top of the shale in central Tennessee, he has so far failed to substantiate it by evidence. Fossils are found in this shale in the northern areas indicating that its age is late Devonic. Conodonts and the spores of freshwater Rhizocarps are among the most characteristic fossils found, and the former occur in many southern exposures of the shale. Zittel and Rohen have clearly shown that these organisms are referable to œsophageal teeth of annelids. Such organisms are today very characteristic of the muds and sands of shallow shores and lagoons. The few marine fossils found in the southern exposures west of the Cumberland ridge are either inconclusive as to the age of the shale in that region, or, as in the Noel shale of Missouri and Arkansas, they mark the age as Mississippian. From all this it appears that the Black shale of southern United States is a basal deposit—a residual soil of an ancient peneplain, very fine and very carbonaceous, and the result in many places of the solution of calcareous strata. This soil was worked over by the transgressing Mississippian sea, which rearranged it, washed it from the higher points, and collected it in greater thickness in the depressions of the old peneplain. As the water deepened, deposition of calcareous shales or of limestones followed, the transition being a perfect one—sometimes gradual, sometimes abrupt.

If the view that the Black shale is the shore deposit of the sea, which farther out deposited calcareous strata, is not accepted, a serious difficulty confronts us; for if we assume, with Ulrich and others, that after the deposition of the Black shale the sea retreated, and then readvanced, we must account for the absence at the base of the calcareous strata of a shore facies; for, surely, if the strata were successively deposited one by one, each later overlapping the preceding one, the point of contact between these strata and the Black shale, which point, at the time of deposition of that stratum must have been the shore, should show some evidence of that fact in the coarser clastic character of the strata and in their inclusion of some fragments of the Black shale surface of the old-land. That no such evidence is found clearly proves that the Black shale represents the shore facies of each succeeding limestone or calcareous shale stratum, and that it is hence not of uniform age throughout, but varies from place to place. If we accept this view—and there seems to

† C. W. Hayes: The Tennessee phosphates, Seventeenth Ann. Rept. U. S. Geological Survey, pt. vi, p. 610.

be no escape from it—the name Ohio shale, adopted for a black shale of Upper Devonic age, which was probably deposited at the mouth of a great river, is not applicable to the Black shale of the southern Appalachians; but the name Chattanooga shale may be applied, if it is dissociated from the idea of any definite age relations.

It may be recalled in conclusion that stratigraphers have not hesitated to consider the base of the Black shale as rising in the scale through the Devonic, but they have been reluctant to carry it higher than that horizon. Williams alone of recent writers has suggested that the Black shale did continue on into the Mississippian; but he, also, has considered the basal portion in all exposures as Devonic. The evidence to the contrary is, however, so overwhelming, and the explanation here set forth accounts so perfectly for all the observed phenomenon, that the old assumption of the synchroneity of the different parts of this formation can no longer stand, since it has no basis in fact.

Statement of the Principle of the Regressive Overlap

This term is applied to the arrangement of strata produced by a retreating sea, the result either of a progressive elevation of the sea bottom or of stationary conditions with a continued supply of detritus. A slow rate of subsidence of the sea bottom, with an excessive supply of detritus, such as might result through a change in the climate from dry to moist, would have essentially similar results.

A slowly retreating sea will carry the shore zone seaward—that is, in the direction of retreat. As a result, the shore detritus will be carried farther out with reference to the original position of the seashore. In other words, the various belts of shore-derived detritus will migrate in the direction of shore retreat and at approximately the same rate. The migrating belts of shore detritus will thus pass successively over areas of formerly deeper water, and hence over areas of offshore deposition. If the retreat is a gradual one, the upward gradation from offshore to nearshore deposits, or in general from fine to coarse deposits, will be a gradual one. In any case, however, the result will be the formation of a conglomerate or sandstone of emergence* or a retreatal conglomerate or sandstone bed. Since, however, during the retreat offshore deposits are continually forming at a distance from shore, we may consider that in

* A. Rutot: Les phénomène de la Sedimentation marine, Bull. du Musée Royal d'Hist. Nat. d. Belgique, ii, p. 41, 1883. I am indebted to Dr A. C. Lane for calling my attention to this author, who has treated some of the principles here discussed. The reference came too late to be made use of in the body of the paper. Reference should also be made to Dr A. W. G. Wilson's paper, in Can. Rec. Sci., July, 1903, vol. 9, no. 2, this author also recognizing the bearing of these principles.

the region unaffected by the shore detritus, even during the retreat, a continuous and uniform, or nearly uniform, series of deposits is accumulating. Even within the outermost zone affected by the retreat—that is, the region reached by the shore detritus at the end of the regressive movement—continuous deposition of offshore sediments is accumulating, until near the end of the movement, when shore detritus will replace the more open-water sediment. It thus becomes apparent that an additional series of strata is forming in the offshore district of which there is no representation in the nearer-shore area. When the retreat is a slow one a considerable amount of sedimentation may result in the offshore area. If the retreat of the sea is rapid, a relatively small amount of sedimentation records it. In any case the amount of sedimentation in any area over that of another area in the line of retreat becomes a measure of the interval occupied by the retreat of the sea from one to the other point. This implies, of course, that the amount of sedimentation

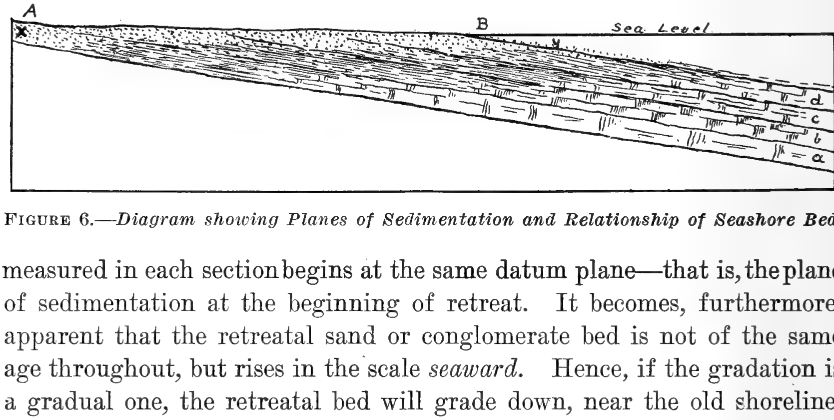


FIGURE 6.—*Diagram showing Planes of Sedimentation and Relationship of Seashore Bed.*

measured in each section begins at the same datum plane—that is, the plane of sedimentation at the beginning of retreat. It becomes, furthermore, apparent that the retreatal sand or conglomerate bed is not of the same age throughout, but rises in the scale *seaward.* Hence, if the gradation is a gradual one, the retreatal bed will grade down, near the old shoreline, into and may contain the fossils of a bed very much older than the bed into which it will grade at a distance from the old shore; for during the period of retreat a considerable space of time has been consumed and a certain amount of sediment has collected at the point eventually reached by the farthest retreat. The relationships of the beds are indicated in the diagram, figure 6.

In this diagram each bed from *a* to *d* was in turn laid down during the retreat, each later bed reaching to a less extent upon the old shore and each bed ending in a sand member. Thus bed *b* does not extend as far as bed *a,* nor *c* as far as *b,* but each ends landward in a sand facies; and these sand ends together constitute a more or less continuous bed of sand passing diagonally across the beds *a-d.* It is evident that the thickness of the beds *a-d* at the point *B* is a depositional measure of the time consumed

in the retreat of the sea from *A* to *B;* and that the retreatal sandstone bed *x-y* is of much later age at *B,* where it represents bed *d,* than at *A,* where it represents bed *a.* If this retreatal bed contains fossils in its basal portion, they will be fossils of successively higher formations when traced from *A* to *B.*

Where the land is sufficiently elevated during this retreat of the sea stream erosion will set in and the material left by the retreating sea may be removed by this process. Furthermore, since elevation of the land is responsible for the retreat of the sea, the streams coming from the higher land will have their slope, and hence their velocity, accentuated. As a result, more detrital material is carried down, and where erosion is not going on deposition of land-derived detritus will take place. Thus pebbles derived from the old-land or from old conglomerates may be carried out for great distances over the emerging coastal plain. Wind deposits of assorted sands with rounded and pitted grains will likewise accumulate on this plain; and remains of land plants and of land and fresh-water animals may be buried in these sands. These sands, being wind or river deposits, will often show cross-bedding and wind ripples.

Examples of regressively overlapping or, better, off-lapping formations are frequently met. Since, however, in the most typical cases available for investigation the conditions are complicated by the structures resulting from the readvance of the sea, a brief account of these complicated phenomena may first be given.

Compound Regressive and Transgressive Overlap

STATEMENT OF THE PRINCIPLES

After the retreat of the sea and the washing seaward, during this retreat, of the land-derived detritus, a period of readvance, we may assume, invariably sets in, because stationary conditions in nature, if they ever occur, are so rare as to be negligible.

The readvance will, of course, have all the characteristics of a first advance, except that the material of which the basal bed of the readvancing series is formed is that of the retreatal bed deposited during the regressive movement and the river deposits and sand dunes accumulated on the recently emerged coastal plain. Thus the retreatal sands and pebbles will be reworked by the advancing sea and incorporated in the progressively overlapping beds of this readvance as a basal or shore facies. If the deposit by wind and streams on the emerged coastal plain was a heavy one, the advancing sea will work over only the upper portion, leaving the middle and lower portions undisturbed. Thus the resulting bed may be a wholly non-marine deposit in the middle, and yet grade

downward into a marine series belonging to the lower and upward into a marine series belonging to the upper formation. Such a sandstone will occupy a stratigraphic gap which widens progressively toward the shore; for it was this region that the retreating sea first laid bare, and it is this region that the advancing sea covers last. Thus the time interval represented by the top and the bottom of the sandstone formation widens more and more toward the shore of the period, while seaward it decreases until it finally dies away, and with it, generally, the sandstone. These relationships are expressed in the following diagrams:

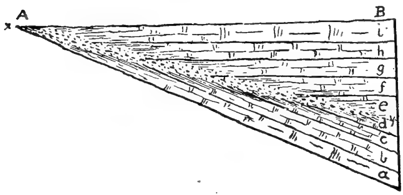


FIGURE 7.—*Diagrammatic Illustration of compound Overlap; actual relationship.*

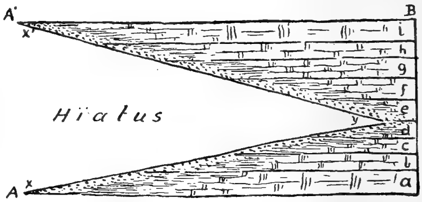


FIGURE 8.—*Diagrammatic Illustration of compound Overlap; showing the hiatus.*

Figure 7 represents the conditions as they will actually appear after a period of combined retreat and readvance. Beds *a* to *d* are deposited during the retreat of the sea; beds *e* to *i* during the readvance. *x–y* is the retreatal sandstone reworked by the advancing sea and made into a basal bed. At *A* it fills the interval between *a* and *i;* at *B* it forms the dividing line between *d* and *E* and is no more than the basal part of bed *e,* the stratigraphic break of *A* having disappeared entirely. At *B,* then, the sandstone *x–y* is wholly marine and may contain fossils intermediate between those of *d* and *f,* or the fosssils of the deeper-water bed *e,* farther out. This relationship is expressed in figure 8, where the widening gap from *y* to *x–x'* represents the increasing time interval comprised within the sandstone member. It need hardly be said, that in nature the beds of the lower and upper series will be so nearly parallel as to seem absolutely so.

It is evident that such a retreatal-transgressive sandstone can not serve as a horizon marker, since it not only varies in age in different localities, but also includes within itself a hiatus which widens progressively toward the source of the material.

APPLICATION OF THE PRINCIPLES

*The Saint Peter sandstone.**—Although there are numerous examples of retreatal-transgressive beds, only two cases, the Saint Peter sandstone

* C. P. Berkey: Paleography of Saint Peter time, Bull. Geol. Soc. Am., vol. 17, pp. 229-250.

and the Dakota sandstone, have so far been worked out in any detail. These will be sufficient, however, to illustrate the foregoing principle.

The Saint Peter formation is typically developed in the upper Mississippian region. In Minnesota it is a friable quartz sandstone of extreme purity in most cases. An analysis of material south of Saint Paul give:*

SiO_2	99.78
Fe_2O_3	trace
MgO	trace

Sometimes, however, impurities in the form of kaolin or iron stain occur. The sandstone is mostly of a white color. "This white color is due to the condition of the surfaces of the grains; they are worn simply to a dead finish—not polished, as can readily be seen by immersing them in water, when they become limpid."† In texture the sandstone is somewhat coarser in the bottom than in the middle and upper beds, but no conglomeratic texture is known. In Wisconsin, however, dolomitic pebbles from the underlying rock are included in its base, this being also more or less eroded.‡ The occurrence in the upper portion of *Hormotoma gracilis* (Hall) and *Lophospira perangulata* (Hall) shows its close relation to the overlying Stones River beds, with which it is perfectly conformable.

One of the most striking features of this formation in Minnesota is the fact that its base is perfectly conformable with the underlying Lower Magnesian limestone (Shakopee), while its top is also perfectly conformable with the overlying Stones River formation. "Nowhere," say Hall and Sardeson,§ "is there any indication, however slight, of an unconformity [between the Saint Peter and the overlying rock]. The transition zone of a green shaly calcareous sandstone shows the steady oncoming of the Lower Silurian [Ordovicic] sea. . . . The Saint Peter has a thickness varying from 75 to 164 feet in Minnesota. It rests, as noted, conformably on the Lower Magnesian or Shakopee dolomite, which, with the New Richmond and Oneota, is, as shown by Berkey and others, a normal depositional successor of the late Cambric. The thickness of the lower Magnesian (Oneota to Shakopee) varies from 105 to 260 feet,‖ and the fossils show it to be of basal Ordovicic age. The beds overlying the Saint Peter are 32 feet thick¶ and are conform-

* Hall and Sardeson: Bull. Geol. Soc. Am., vol. 3, 1892, p. 351.
† Hall and Sardeson: Loc. cit., p. 351.
‡ T. C. Chamberlin: Geology of Wisconsin, vol. ii, 1877, p. 287.
§ Loc. cit., p. 355.
‖ Hall and Sardeson: Loc. cit., p. 368.
¶ Winchell and Ulrich: Paleontology of Minnesota, vol. ii, introduction.

ably succeeded by the Black river. This and the fossils found in them show these beds to be the highest Stones River (Chazy) and equivalent to the Lowville or Birdseye of New York. In the Champlain valley the Beekmantown is at least 1,800 feet thick,* while the Chazy is nearly 900 feet thick on Valcour island,† the lowest beds not being shown.

It thus appears that the Saint Peter sandstone of Minnesota fills the interval represented in the lake Champlain region by the deposition of over 1,500 feet of Beekmantown dolomites and more than 800 feet of Chazy limestones. Its perfect conformity with the overlying and underlying beds proves that this great hiatus lies within the sandstone itself.

In eastern Tennessee the Knox dolomite has a thickness of about 4,000 feet, of which the upper half, if not more, is basal Ordovicic. It is succeeded by the Maclurea limestone (Chazy, with *Maclurea magna*), which has a maximum thickness of 600 feet, and this is followed by several hunderd feet of upper Stones River. In central Tennessee the Stones River group is 360 feet thick, at Cincinnati 500 feet, and in central Kentucky about 375 feet. In all these cases it is underlain by a representative of the Saint Peter sandstone.‡

In the Arbuckle mountains of Indian Territory the upper 1,250 feet or more of the Arbuckle limestone are of the age of the Beekmantown of New York—that is, basal Ordovicic. A slight erosion interval and some beds of pure sand separate this formation from the overlying Simpson series, which has a maximum thickness of 2,000 feet. It includes at least one heavy bed of sandstone near the center. The fauna of the lower half of the formation (below the sandstone) is that of the Chazy of New York, while that of the upper half is similar to the fauna of the upper Stones River of central Tennessee or of the Stones River beds lying between the Saint Peter and Black River, in the Minnesota area. It thus becomes clear that in the Arbuckle Mountain area as well as in eastern Tennessee the whole or nearly the whole of the basal Ordovicic (Beekmantown) was deposited while the sea retreated from the Lake Superior region. That the Arbuckle region was also laid bare toward the end of this retreat is shown by the erosion plane between the Arbuckle and Simpson formations. During the readvance of the sea the lower Chazy beds were laid down in the Arbuckle region, but, as before noted, they thin away northward. This thinning away of basal beds continued throughout the period of advance, until only the upper 32 feet of Chazy (Upper Stones River) were deposited in the Minnesota region. Thus the

* Brainard and Seeley: Bull. Am. Mus. Nat. Hist., vol. iii, 1890, pp. 2, 3.

† Brainard and Seeley: Ibid., vol. viii, pp. 305-315. Bull. Geol. Soc. Am., vol. ii, 1891, pp. 293-300.

‡ Winchell and Ulrich: Loc. cit., p. xciv.

break included within the Saint Peter sandstone of Minnesota is equivalent to the upper thousand feet of the Arbuckle plus the lower 1,900 feet or more of the Simpson formations, since this latter formation is followed by beds with a Black River fauna (lower Viola limestone). These relationships are graphically shown in the following diagram:

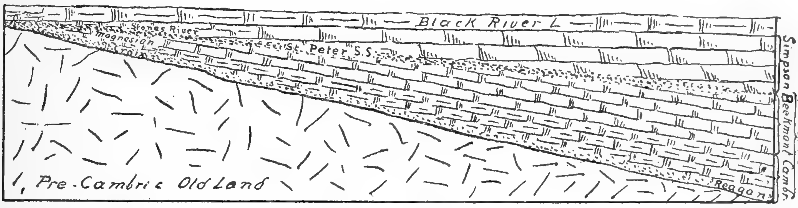


FIGURE 9.—*Relationship of the Arbuckle and Simpson and the Stones River and Magnesian Formations, and position of the Saint Peter Sandstone.*

In the Nittany valley of Pennsylvania* (Center county) the Beekmantown consists of nearly 2,500 feet of limestones, sometimes brecciated, often dolomitic and with siliceous sands at the base. *Ophileta complanata* occurs about 200 feet above the exposed base, but the lowest beds are not shown in this section. Toward the middle occurs *Asaphus marginalis* and *Ribeiria calcifera,* and toward the top of the series *Bathyurus amplimarginatus, Maclurea affinis, Liospira strigata, Protowarthia rossi,* and *Dalmanella subæquata gibbosa.* This fauna, as remarked by Collie, is an Upper Beekmantown fauna.

The fossiliferous beds are succeeded by 2,335 feet of ". . . compact yellowish gray and drab dolomitic limestone frequently thin bedded and laminated, alternating with numerous thin beds of dark limestone, weathering to a light gray color. Nodules of chert occur frequently, and in such occurrence the rock tends to be arenaceous." This is also referred to the Beekmantown by Collie, but may be of later age. It is followed by 235 feet of carbonaceous crystalline black limestone alternating with gray limestone and containing *Leperditia fabulites, Protorhynchula ridleyana,* and other fossils of Upper Stones River age. Succeeding this are 93 feet of Black River and 603 feet of Trenton limestone.

Since the fossiliferous horizon below the 2,335 feet of unfossiliferous (?) beds is upper Beekmantown and the first fossiliferous horizon is Upper Stones River (Upper Chazy), the lower Stones River, or Chazy proper, seems to be represented by this unfossiliferous (?) horizon. If, then, this series is taken from the Beekmantown and added to the Chazy, we have 2,500 feet—of the former and 2,500 feet (+) of the latter, a

* George L. Collie: Ordovician system near Bellefonte, Pennsylvania. Bull. Geol. Soc. Am., vol. 14, pp. 407-420.

division which agrees more fully with the Arbuckle Mountain section. Comparing with this the Mohawk River section, 250 miles to the north, we find a striking discrepancy. In the Mohawk section less than 500 feet of Beekmantown rest with a basal conglomerate upon the Adirondack gneisses, and is followed after an erosion interval by at the most 30 feet of Lowville (= Upper Stones River or Upper Chazy). This is conformably succeeded by the Black River and Trenton limestones.

It is evident that we have here much the same relationship that exists between the Upper Mississippi region and the Arbuckle Mountain section; only, in the case of the eastern section, no sands were deposited during the period of retreat, and hence none during the advance. While the Beekmantown of the Mohawk valley is probably not lowest Beekmantown, and although some erosion went on, during the retreat of the sea, in the exposed area, nevertheless it seems not unlikely that at least 1,000 feet of Beekmantown were deposited in central Pennsylvania during the period of retreat, while, if the reference of the "barren" beds to the Chazy is correct, nearly 2,500 feet of limestones were forming in Pennsylvania during the readvance. If the barren beds are Beekmantown, the amount of deposition in Pennsylvania during the readvance would only be about 200 feet, which amount agrees more nearly with the rate of deposition shown in the Arbuckle region during the Saint Peter advance.

The case here set forth takes account only of the greater movements and their results. That there were minor movements is shown by the several sandstones intercalated in the Simpson formation of the Arbuckle mountains and in the Ozark series of Missouri. These, however, did not alter the main course of events to any perceptible degree.

The Dakota Sandstone problem.—The Dakota sandstone presents another interesting problem of a retreatal sandstone worked over by a readvancing sea. As already noted, the marine sedimentation at the end of Fredericksburg or the beginning of Washita time extended northward as far as central Colorado. On the Purgatoire river, where the Dakota is 100 feet thick, it is underlain by 50 to 100 feet of dark shales and shaly sandstones similar to the Dakota and carrying in the shaly portion

Inoceramus comancheanus Cragin.	*Pholadomya sancti-sabæ* Roemer.
Trigonia emoryi Conrad?	*Protocardia texana* Conrad.
Cardium kansasense Meek.	*Leptosolen conradi* Meek.
Cyprimeria sp.	*Tapes* sp.

This rests on 15 to 60 feet of coarse gray cross-bedded sandstone, which in turn rests on the Morrison beds.* Similar conditions exist in Oklahoma and New Mexico.

* Stanton: Journal of Geology, vol. xiii, 1905, pp. 657-669.

At Two Buttes uplift, in southern Colorado, the shales beneath the Dakota furnish further

Gryphœa corrugata Say. *Pachydiscus brazoensis* (Shumard).

and others. The beds appear to rest directly on the eroded surface of the Red beds.

On the Cimarron, in western Oklahoma, the fossiliferous Comanche beds beneath the Dakota are dark shales, with layers of brown flaggy sandstone and bands of somewhat calcareous sandstone 50 to 60 feet thick. They contain

Gryphœa corrugata Say.
Ostrœa subovata Shumard.
O. quadriplicata Shumard.
Plicatula incongrua Conrad.
Inoceramus comancheanus Cragin.
Gervilliensis invaginata White.
Trigonia emoryi Conrad.
Protocardia multilineata Shumard.
Pholadomya sancti-sabœ Roemer.
Anchura kiowana Cragin?
Turritella seriatim-granulata Roemer.
Hamites fremonti Marcou?
Pachydiscus brazoensis (Shumard).

Below these beds, and resting with apparent disconformity on the Morrison, are coarse cross-bedded sandstones with irregular bands of pebbles, varying from 4 to 15 feet in thickness.

This horizon with *Gryphæa corrugata* was traced westward to about 30 miles east of Folsom, New Mexico. At Tucumcari 60 feet of fossiliferous shales and sandstones underlie the Dakota, and at Canyon City, Colorado, 85 feet of these shales and thin bedded sandstones underlie the Dakota, and are separated from the Morrison by 35 feet of massive gray sandstone with bands of fine conglomerate near the top.

These beds are correlated with the Kiowa and Mentor beds of Kansas (Stanton). Regarding the age of these beds, Cragin* considered that they "represent a group of sediments intermediate between the Fredericksburg and Washita division, and one which, as a meeting ground of the faunas of these two divisions, can not satisfactorily be referred to either."† Hill,‡ on the other hand, holds that the beds "represent the modified, attenuated northern portion of the Washita division, and probably a portion of the Fredericksburg division of the Comanche series of Texas." Though there is a difference here as to the classification of the "Kiowa division," as Cragin proposed to call it, there is unanimity in regarding it as representing the border line of the Fredericksburg and Washita.

At Marquette, McPherson county, Kansas, the following sections occurs:§

* American Geologist, vol. xvi, pp. 357-386.
† Ibid.: Loc. cit., p. 383
‡ Am. Jour. Sci., 3d ser., vol. 49, pp. 205-235.
§ C. N. Gould: American Geologist, vol. 25, pp. 35, 36.

		Feet
11.	Equus bed	±50
10.	Dark brown to black sandstone, forming prominent escarpments, very fossiliferous in a layer 1 to 2 feet thick in the middle of the ledge. The fossils are listed by Gould.*	8
9.	Soft yellow sandstone	2
8.	Hard massive gray and yellowish sandstone	4
7.	Yellowish and bluish shales	16
6.	Rather hard yellowish sandstone	8
5.	Bluish to yellowish paper shales, very like Kiowa, with selenite and cone-in-cone gypsum; contains layers of soft yellow sandstone with dicotyledonous leaves	40
4.	Two six-inch ledges of very fossiliferous limestone separated by shales. The fossils are listed by Gould.†	3
3.	Shales like the Kiowa, with iron pyrites, selenite, and cone-in-cone gypsum	20
2.	Gray to yellowish sandstone, with much lignite and crushed plant material in places; very like Cheyenne	4
	Total Comanche-Dakota	105
	Disconformity.	
1.	Permian shales, red, blue, green, etc.	

The sandstone number 10 has all the appearance of the Dakota sandstone and lies 50 feet above the stratum in which the first disotyledonous plant remains are found. Lithically this entire series belongs in the base of the Dakota. Similiar conditions exist at Mentor, 20 miles northeast, but the exposures are not so satisfactory.

The fauna of both the lower and upper beds is that of the Kiowa shales. In the typical section this comprises 125 to 150 feet of bluish gray paper shale, becoming more arenaceous upward. Interspersed throughout the formation are layers of hard gray limestone, soft sandstone, and pebbles. Gypsum occurs throughout and the shales are fossiliferous. The fauna as listed by Cragin‡ contains 51 species of intertebrates and 13 species of vertebrates.

The base of the Kiowa shales of Kansas is formed by the Champion shell-bed, a thin stratum of shell conglomerate commonly less than a foot in thickness and rarely more than a foot and a half. *Gryphæa hilli* is the only fossil found in it in some localities, but elsewhere a considerable number of species have been found. Of 36 species listed by Cragin, 22 pass upward into the Kiowa shale, the remainder apparently not occurring above the shell-bed. Among these latter is *Gryphæa hilli,* which

* Ibid., p. 37.
† Loc. cit., pp. 36, 37.
‡ American Geologist, vol. xvi, 1895, pp. 372, 373.

is an abundant and characteristic fossil of the Comanche Peak and Walnut beds (Fredericksburg) of Texas. A number of other characteristic species of this bed do not occur above the Fredericksburg horizon in Texas. On this account Cragin thinks that . . . "the Champion shell-bed should be referred to the Fredericksburg division and perhaps to a horizon not higher than the middle of that division."*

The Champion shell-bed is underlain by the Cheyenne sandstone, which rests disconformably on the Red beds. It consists of soft variegated grayish or yellowish cross-bedded sandstones in the lower part, with pebbles of quartz, clay granite, etc., smoothly water-worn and ranging in size up to a hen's egg. They are often seen in pockets on the Red beds. Lignite and other carbonaceous matter also occurs here. The upper part consists of alternating vari-colored sandstones, sandy shales, and hard argillaceous shales. The total thickness ranges from 50 to 100 feet. From the upper part of this sandstone dicotyledonous plants of the genera Rhus, Sassafras, Sequoya, etc., are obtained. No animal remains have been recorded from this formation, which is probably entirely of continental origin.

In the Arbuckle mountains of Indian Territory the Cretacic beds rest on a nearly flat floor of older rocks. The base consists of approximately 240 feet of sands, with local conglomerates at the bottom. They are succeeded by the Goodland limestone, 20 to 30 feet thick, and a nearly pure limestone formation. Above this lie the Kiamitia clays, Caddo limestone, Bokchito formation, and Bennington limestone, aggregating nearly 840 feet in thickness. The upper beds are slightly eroded and succeeded by the Silo sandstone, which is in part at least of Dakota age.†

The Goodland limestone is correlated with the entire Fredericksburg—that is, Walnut, Comanche Peak, and Edwards—while the underlying sands are called Trinity. This correlation is no doubt just as erroneous as was the former reference of the Cheyenne sandstone to the Trinity. The fact that a lower Cretacic formation is a basement sand does not make it Trinity in age, since basement sands can be of any age. The combined thickness of the Comanche Peak and Edwards (the Walnut is only a phase of these limestones) on the Rio Grande is in the neighborhood of 700 feet, while in Mexico it is still greater. This shows clearly that the Goodland limestone can represent only a part—that is, the upper part, though probably not the highest part—of the Fredericksburg, and that the so-called Trinity sands are really basal sands of Fredericksburg

* Cragin: Loc. cit., p. 371.

† Taff: Professional paper no. 31, U. S. Geological Survey, Tishomingo and Atoka folios.

age which have overlapped the Trinity. Here, as in the case of the Cheyenne sandstone, the simple application of the principle of progressive overlap will give the right solution of the problem.

The Kiamitia clay is equivalent to the Kiowa shales of Kansas, both being at the Fredericksburg-Washita boundary. The Caddo, Bokchito, and Bennington formations, however, are later Washita beds. Here, then, we have clear evidence that the Dakota retreat, beginning in central Colorado and Kansas at the commencement of Washita time, reached the Arbuckle Mountains region only toward the middle of that period, after nearly 700 feet of additional strata had been deposited in this more southern region.

It is not at all improbable that while the Kiowa (Kiamitia) clays were forming the upper Edwards limestone of southern Texas and Mexico was still being deposited.

In northern Texas the Washita division is about 500 feet thick and consists of clays, marls, and some limestone beds, the whole resting conformably on the Goodland limestone. At the base lie the Kiamitia clays with *Gryphæa corrugata,* while the top is formed by the Grayson marls, which are apparently conformably succeeded by the Dexter sands of the Woodbine (Dakota). In the Austin region the corresponding deposits (Georgetown, Del Rio, and Buda) are chiefly limestones, some of them even chalk of foraminiferal origin; hence it is not surprising to find the series much thinner in that section. The top of the section, moreover, is here marked by an erosion interval, and hence the whole of the Buda (elsewhere 100 feet thick) is not shown. This erosion interval is important as indicating the extent to which the Dakota retreat took place, the Austin region being lifted into dry land.

The Dakota of Texas is known as the Woodbine. In the northern section it is at least 600 feet thick, at Denison about 500 feet, and at Fort Worth about 300 feet. Near Waco it has thinned to 45 feet, and on the Brazos it has disappeared altogether. Hill states that it apparently rests unconformably on the Grayson marls and Main Street limestone of the Denison beds of the Washita division. "The upper beds pass by inseparable transition from sands into sandy clays and finally into the bituminous clays of the Eagle Ford formation. This transition is so gradual that no exact line of separation can be drawn between the Woodbine and Eagle Ford formations. The parting is arbitrarily established at the zone of *Exogyra columbella,* which is considered as the top of the Woodbine formation."* The disconformity at the base of the section can not be great, if it exists at all. Of course, the emergence at the

* R. T. Hill: Twenty-first Ann. Rept. U. S. Geological Survey, pt. vii, p. 296.

beginning of Woodbine deposition (Dexter sands) would allow a certain amount of erosion, probably by the streams which later spread out the Dexter sands. The presence of dicotyledonous plants and the absence of marine organisms indicate that these sands were spread by streams. Sometimes a clay marks the transition from the Grayson marls. The presence of glauconite in the lower beds suggests that at first they were deposited in a shallow sea, and that only during the progress of deposition of the sands did emergence occur. If this is the case, there can be no serious break between the Grayson marls and the basal Dexter sands, and from the description of the sections there appears to be none. False bedded structure is a characteristic feature of these sands, whose thickness is approximately 160 feet.

It was apparently during this period of emergence that the erosion at Austin took place. This is believed to be the case, because the succeeding beds of the Woodbine (Lewisville beds) carry a marine fauna, and hence mark the readvance of the sea. The Lewisville beds consist of laminated lignitic sands and clays, interstratified with brown sands, ferruginous sandstones, and argillaceous shelly sandstones, aggregating 100 feet. The fauna of this bed, listed by Hill,* is peculiar, in that it is unknown above or below this horizon. This indicates a considerable period to have elapsed before the readvance of the sea took place. The higher beds of the Woodbine are sands and clays, often fossiliferous, and pass upward into the overlying Eagle Ford formation.

The Eagle Ford formation of Texas is essentially a bituminous clay. It rests directly on the Buda limestone in central Texas, having there become a flaggy argillaceous limestone. The thickness of the formation varies considerably, from 250 feet on the Rio Grande to 600 feet in northern Texas, with varying thicknesses at other points. In the Austin region it is only 30 feet thick, but here only the upper beds of the formation rest upon the post-Buda erosion plane.

In southern Kansas the typical Dakota sandstone is followed by lignitic sands, bituminous shales, and saliferous and gypsiferous shales with marine fossils, followed by 350 to 400 feet of shales and limestones with the typical fauna of the lower Colorado or Benton group, *Inoceramus labiatus* predominating.

In the Front Range region of Colorado these shales (Benton) vary in thickness from 500 to 700 feet, while farther north, in the Bighorn Mountains they increase to 1,300 feet, and in the Black Hills to 1,600 feet.† Throughout most of the region the characteristic fauna with

* Hill: Loc. cit., p. 314.

† N. H. Darton: Bull. Geol. Soc. Am., vol. 15, pp. 379-448. Professional paper no. 32, U. S. Geological Survey.

Inoceramus labiatus begins from 200 to 500 feet below the top of the series, in an impure limestone averaging 50 feet in thickness. This limestone (the Greenhorn) apparently represents the successful accomplishment of the post-Dakota marine invasion, the underlying shales, except in the southern area, showing little if any evidence of marine occupation. In fact, it is not improbable that 800 to 900 feet of the Lower Graneros shales and included sandstones of the northern region are chiefly of non-marine origin, representing the continued deposition of fine material during the period of continued southward retreat and early advance of the sea. This would explain the increase in thickness northward of the Graneros shales. The only fossils recorded from these shales in the northern region are dicotyledonous plants and fish scales.

The Carlisle group overlies the Greenhorn (*Inoceramus labiatus*) limestones and constitutes the upper member of the Benton division. This group consists mostly of clays, with some limestones and sandstones. It is as a whole not very fossiliferous, but certain beds are characterized by *Prionocyclus wyomingensis* and *Prionotropis woolgari.*

The Eagle Ford beds are succeeded by the Austin chalk with a thickness of 600 feet in central Texas, but 1,500 feet on the Rio Grande. In Colorado this series is represented by the Niobrara formation, with *Inocoramus deformis* and *Ostrea congesta.* This is 700 feet thick in southern Colorado, where it rests on about 200 feet of Benton, Northward, in the Black hills, where the Carlisle has a thickness of from 500 to 700 feet, the Niobrara is only about 200 feet thick, thinning to 100 feet toward the northwest.

Above the Niobrara comes a great thickness of clay shales, the Pierre. These have a recorded thickness of 4,000 feet in southern Colorado, increasing to over 7,000 feet in the Denver region, but decreasing to 2,700 feet in the Bighorn mountains and to 1,200 feet in the Black hills. Beds of sandstone become intercalated in the thicker sections, as at Denver, where a bed of sandstone from 100 to 350 feet thick occurs near the middle. The succeeding Fox Hill beds, which are mainly sandstones, have an average thickness of 300 feet or less, though increasing to 1,000 feet in the Denver region. Marine fossils occur, together with plant remains, the whole series grading up into the great non-marine Laramie formation.

In the northern region the Austin chalk grades up into the Taylor marls and Eagle Pass or Navarro formation. These are the *Exogyra ponderosa* beds. The Taylor marls are about 700 feet thick in southern Texas, and 600 feet in central Texas. The overlying Navarro has a thickness of 4,300 feet on the Rio Grande and consists mainly of sand-

stones with beds of clay and glauconite and with several coal seams about 1,200 feet above the base. Marine fossils occur almost throughout the series, but Laramie plants have been found in the neighborhood of the coals.

The interpretation of these sections in the light of the principles discussed shows us that the Dakota sandstone represents the deposits between the retreat and readvance of the sea. The retreat, as we have seen, began in Washita time, almost at the beginning of that period. The Washita division itself is the depositional equivalent of the retreatal Dakota sandstone, and hence the lower Dakota is actually of Washita age—of lowest Washita in the northern and of highest Washita in the southern area. The retreat of the sea was considerable, as shown by the unconformity between the Buda and the Eagle Ford and by the thinness of the latter. With the readvance of the sea, a new fauna, an immigrant from Europe, came in; and as the sea continued to advance, the continental sands of the Dakota-Woodbine Graneros were reworked and incorporated as basal deposits of later Cretacic age. The Upper Dakota sandstone is thus of Eagle Ford-Benton age, the return of the sea being finally accomplished in mid-Benton time.

From this it appears that the Dakota sandstone can not be included as a time element of the standard scale, since it represents different time in different localities. This consideration also suggests that the Washita be made the base of the Middle Cretacic, the classification being approximately the following:

		Marine.	Non-marine.
Upper Cretacic-Montanan		Navarro	Laramie.
		Taylor.	
Mid-Cretacic	Coloradoan	Austin.	
		Eagle Ford.	
	Unrepresented interval.		Dakota.
	Washitan.		
Lower Cretacic-Comanchean		Fredericksburg.	
		Trinity.	

If two systems are to be made from the present Cretacic, the Comanchic system would end with the Washitan, and the Cretacic begin with the Coloradoan, the unknown base of which must be looked for in southern Texas or in Mexico.

Non-marine Progressive Overlap

EXPLANATION OF THE TERM

This term is applied to the large structure normally produced during the formation of a great fan or subaerial delta from the wash carried by

the streams from the mountains and deposited on the plains adjoining. Such a subaerial fan will, of course, grow year by year; and in so growing the latest deposits, whether derived from the mountains or whether obtained through the reworking of the previously deposited portion, will, as a rule, extend farther out on the plain than did the deposits of previous periods. In other words, each later formation will overlap the previous ones by a margin commensurate with the increase in the size of the fan, and beyond the margin of the previously formed bed it will come to rest directly on the floor of the plain. This overlapping of later formed over earlier beds will, of course, be progressive, if the growth of the fan is continuous. The essential point of difference between this type of overlap and that formed in a transgressing sea is that in the subaerial fan the formations will overlap one another in the direction *away from the source of supply of the material;* while in marine progressive overlap (transgressive) the overlap is *toward the source of supply of the material.* The following diagrams will illustrate this difference, the source of supply in each case being on the left.

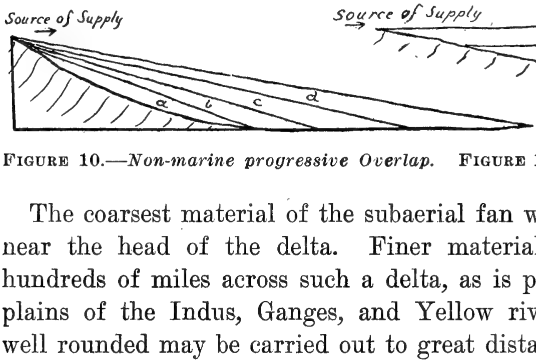


FIGURE 10.—*Non-marine progressive Overlap.*

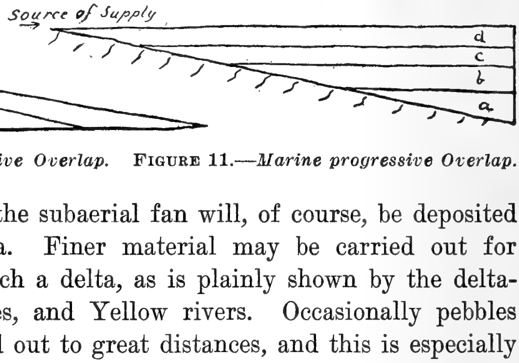


FIGURE 11.—*Marine progressive Overlap.*

The coarsest material of the subaerial fan will, of course, be deposited near the head of the delta. Finer material may be carried out for hundreds of miles across such a delta, as is plainly shown by the delta-plains of the Indus, Ganges, and Yellow rivers. Occasionally pebbles well rounded may be carried out to great distances, and this is especially true of the well rounded pebbles derived from older conglomerates. When the surface of the delta has become very flat, drainage obstructions may take place, in which case swamps and deposits of carbonized plant remains will form. Thus a fossil delta of this type may include coal seams, the tops of which may again be eroded or covered with a moderately coarse river deposit.

Another type of non-marine overlap is that connected with a retreating seashore, in which case the overlapping of the non-marine beds will be, not on the old plain surface, but on previously deposited and all but contemporaneous marine beds. Along the border line the two, marine and non-marine, will blend, and it will appear as if the non-marine overlies

the marine, though in reality it is more a replacement of the one by the other. The following diagram will make this clear:

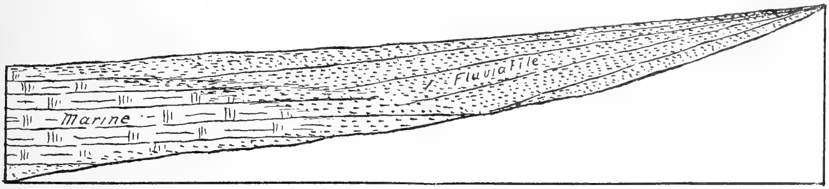


FIGURE 12.—*Overlap Relation of marine and non-marine Beds.*

EXAMPLES OF NON-MARINE PROGRESSIVE OVERLAP

Chemung-Catskill.—A typical example of the last described type of overlap is seen in the case of the Catskill and Chemung formations of New York and the northern Applachians generally. Here the non-marine Catskill begins in Portage time as the Oneonta, and is gradually but progressively pushed westward and northwestward until it has reached the very summit of the Chemung. Thus in the Ithaca region the red sedimentation of the Catskill type does not begin until upper Chemung time. In the Olean region farther west it begins in the Cattaraugus beds above the Chemung (Devono-Carbonic transition). Thus, while the Chemung is fully developed in western New York, it is absent in eastern New York and Pennsylvania, where the Catskill type of sedimentation alone occurs. Between these two points both are seen, the non-marine always overlying the marine. This relationship is shown in the following diagram:

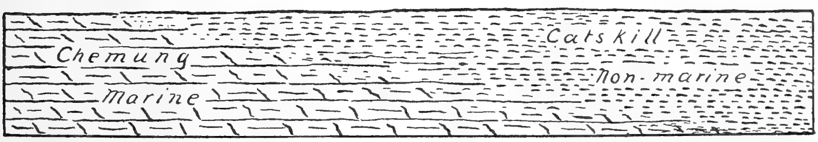


FIGURE 13.—*Overlap Relation of marine Chemung and non-marine Catskill Beds.*

The Pocono.—This is the lowest of the Appalachian Lower Carbonic formations and represents the continued non-marine sedimentation from the Appalachians northwestward to the western Pennsylvania region. The original easternmost extension of this formation, as of the preceding and succeeding non-marine formations, has been removed by erosion; so that we find at the present time only portions which originally were accumulated at some distance from the highland which furnished the material.

That the Pocono is non-marine is shown by the absence of fossils, except as noted below. The fact is further indicated by the relationships of the strata, which conform to the non-marine type of overlap. The source of the material of this formation was in the Appalachian oldlands on the southeast, as is shown by the decreasing coarseness toward the northwest, and by the fact that no land capable of furnishing the material of this rock existed in Ohio, western New York, or Canada, which were extensively covered, at the time of the formation of the Pocono, by marine Devonic strata, many of them limestones. The characters of this formation will be best shown by two sections from the eastern area.

I. *Section of the Pocono in the Northern Anthracite Fields, in Wayne County, Pennsylvania, about 10 Miles South of the New York Line.**

	Feet
8. Sandstone	40
7. Shale and sandstone	200
6. Massive sandstone	125
5. Shale and current bedded sandstone	265
4. Griswold Gap conglomerate	35
3. Sandstone and shale, imperfectly exposed	150
2. Sandstone and sandy shale	200
1. Mount Pleasant conglomerate	25
Total	1,040
0. Catskill.	

Beds 1 to 3 are regarded by White as transitions from the Catskill.

II. *Section at Pottsville.*†

	Feet
6. Sandstone, more or less conglomeratic	521
5. Slate	22
4. Sandstone, with much conglomerate	726
3. Sandstone with little conglomerate	240
2. Sandstone, variegated	409
1. Red, gray, olive, and yellow sandstone, with some shales and conglomerates, transitional from Catskill	525
Total	2,443
0. Catskill.	

On the Susquehanna the formation is 2,000 feet thick. It becomes coarser toward the southeast, the pebbles in Maryland being sometimes

* Stevenson: Lower Carboniferous of the Appalachian basin. Bull. Geol. Soc. Am., vol. 14, 1903, p. 18. (Slightly altered.)

I. C. White: Second Geol. Survey of Pennsylvania, G 5, 1881, p. 56.

† Stevenson: Loc. cit.

three-fourths of an inch in length or over. In this region* interbedded fossiliferous shales occur, showing the proximity of the sea and its occasional invasion of the growing Pottsville fan. In Huntingdon and Bedford counties, Pennsylvania, where the thickness of the formation is from 1,100 to 1,200 feet, and where it is mostly sandstone, a shaly layer with marine fossils (Spirifer, Rhynchonella, and productoid forms) has been discovered 400 feet above the base of the series. This and the Maryland sections are about in a line parallel to the front of the growing fan, as shown by the correspondence of the thickness.

In tracing the Pocono northwestward, we find that in the northwestern part of Lycoming county, Pennsylvania, it consists of 665 feet of current-bedded sandstones, with a one-foot seam of coal lying 80 feet above its base. In the northwest of Lycoming county its thickness is reduced to 350 feet and it is still a current-bedded sandstone. In Potter county, Pennsylvania, we have 330 feet of sediments, with a thin layer of coarse sand or conglomerate, the Shenango, at the top. Westward from this the pebbles become flat, like those of the underlying Chemung sandstones. In McKean county, Pennsylvania, the Pocono is not much over 200 feet thick, the Shenango being 40 feet. In most of these northwestern sections intercalated strata with marine fossils show the presence of the Waverly sea, which laved the front of the great Pocono fan and into which its edge dipped. Downward these beds grade into fossiliferous Lower Carbonic strata, which are the contemporaneous deposits of the eastern end of the Waverly sea. The margin of this sea was gradually pushed westward by the growing fan, as shown by the character of the deposits.

If we glance for a moment at the contemporaneous marine deposits of the Ohio-Michigan area we find that the coarseness of the material decreases toward the northwest. Many sandstone beds, like the Berea, die out in northern Michigan, while beds like the Logan change from conglomerates to sandstones. This indicates the Appalachian source of the material, even of the marine deposits, showing that the streams which built the subaerial fan also supplied the material for the bordering marine strata.

In the summary given by Stevenson† of the Pocono, the vital fact is brought out that the thinning of the Pocono in northwestern Pennsylvania and in West Virginia is due "apparently in part" to "loss of the lower beds." The significance of this fact is best stated in Professor Stevenson's own words:

"The Pocono of Pennsylvania, Ohio, Kentucky, and Virginia has been regarded by most geologists as Lower Carboniferous throughout. The Pocono of

* Maryland Geological Survey, Garrett county, p. 168.
† Stevenson: Loc. cit., pp. 39, 40.

the eastern outcrops in Pennsylvania has been accepted as the equivalent of that in the western counties, as though the westward decrease were due merely to lessened thickness in each of the subdivisions. It must be clear, however, . . . that the loss in thickness is due very largely to disappearance of the lower members of the section, as is the case also southward from central Kentucky and southern Virginia, so that in Alabama and much of Tennessee only the uppermost beds remain. A new correlation appears to be necessary."*

The general change in the character of the sediments from conglomerates and coarse sandstones in the east to shales in the west is also emphasized by Stevenson. The relationships of these deposits may be expressed in the following diagram:

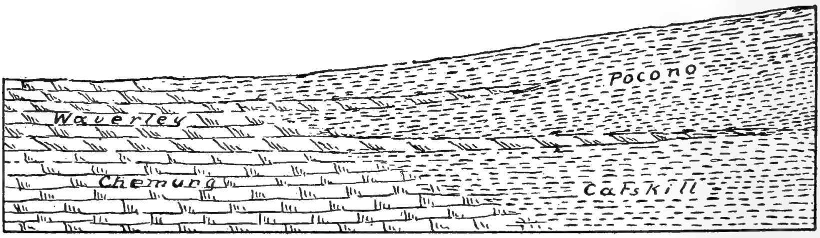


FIGURE 14.—*Relation of Waverley and Chemung Formations to the Pocono and Catskill.*

The Mauch Chunk.—The Mauch Chunk period of Appalachian history seems to have been a period of more stationary conditions, accompanied by some subsidence, as shown by the fact that fine sediments characterize the formation throughout, and also by the presence of extensive marine limestones. In the northern Appalachians heavy non-marine sediments still accumulated. Thus in the type region 2,168 feet of red shales, with some sandstones in the upper part, constitute this formation. A little north of Mauch Chunk, Pennsylvania, the formation of this name has a thickness of 3,342 feet and consists almost wholly of red shales.

In the Broad Top region of Huntingdon county, Pennsylvania, the basal part of the Mauch Chunk consists of 141 feet of shales and sandstones, followed by 49 feet of limestone (Greenbrier), and this by 910 feet of sandstones and shales. In northeastern Lycoming county, 30 miles from Mauch Chunk, the base of the formation consists of 120 feet of shales, followed by 75 feet of marine limestone and 150 feet of shales. In northwestern Lycoming county the basal beds have been reduced to 80 feet, while the upper beds are only 20 feet thick, the intervening limestone measuring 50 feet. In Potter and in McKean counties only the upper beds are present, decreasing from 70 feet in the first to 50 feet in the second, and finally dying away westward as a coaly black shale.

Southward from the type region of non-marine sedimentation the marine phase thickens. Thus on the Potomac, in the Maryland Alle-

ghenies, the formation is 1,107 feet thick and consists at the base of 227 feet of Greenbrier limestone resting directly on the Pocono, followed by 800 feet of shales, mostly red. Southward, in Pendleton county, West Virginia, the Greenbrier limestone at the base is 325 to 400 feet thick, and is followed by gray and brown sandstones and shales and red shales (Canaan shales), with a thickness of 1,250 feet. These shales, however, are in all probability only partly non-marine.

The Mauch Chunk thus seems to present two periods of non-marine fan-building separated by a period of partial subsidence. Non-marine (fluviatile) sedimentation appears to have been continuous in eastern Pennsylvania throughout. In both periods the greatest accumulation of non-marine sedimentation was in the east, and the members overlapped westward and northward. A diagrammatic section will make this clear.

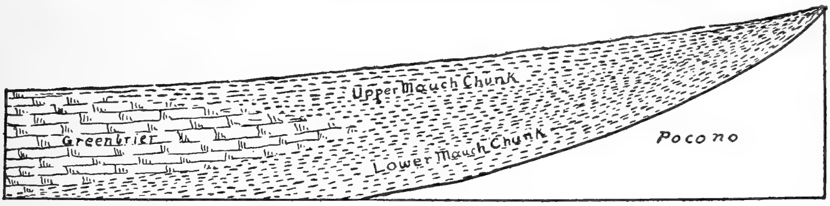


FIGURE 15.—*Relation of the Upper and the Lower Mauch Chunk and the Greenbrier.*

The upper Mauch Chunk fan represents the recovery of the land after the Greenbrier subsidence. With this recovery corresponds the presence of coarser sands in the upper Mauch Chunk in the eastern region, where non-marine sedimentation was uninterrupted. That the land was low and streams sluggish is indicated by the fact that the surfaces of the beds are marked by ripple-marks, sun-cracks, rain-drop impressions, and foot-prints of vertebrates—all signs of floodplain deposits.

The fossils of the Greenbrier in southern Pennsylvania and Maryland correspond to those of the Maxville of Ohio. The Maxville is separated from the Logan by an interval of erosion, which may correspond to early Mauch Chunk sedimentation in the east; for the beginning of a new fan on an older one indicates either an increased supply of detritus or a period of elevation. The fineness of the lower Mauch Chunk is, perhaps, more in harmony with the theory of a renewed elevation of the region, which in the western area permitted the post-Logan erosion. A part of the upper non-marine Pocono probably also suffered erosion during this time. It may perhaps be further surmised that the change indicated was not due to an elevation in the east, but rather to an elevation of the western region, which gave the surface of the Pocono fan so gentle a slope that the streams no longer were able to carry to this western area the detritus derived from the east; and so they dropped it nearer the source, building

up a new fan, but this time of fine materials. However this may be, the presence of the Greenbrier limestone shows a widespread subsidence, and the fossils of this limestone show that this took place at the beginning of Chester time.

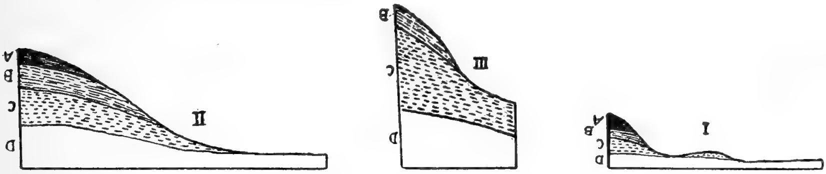
It seems likely that the post-Logan elevation, which in Michigan was accompanied by the formation of gypsum beds (lower Grand Rapids), gave an impulse to the southeastward transgression of the Mississippian sea, and that during this period the Cumberland ridge above outlined was finally submerged. The elevation was felt in the Mississippian valley, since a pronounced line of erosion exists at the top of the Warsaw, which is followed by only the highest Saint Louis limestone, resting with a basal breccia on it. Southward in the Mississippi region this interval becomes less; and southeastward, in the southern Appalachians, it disappears altogether, the Saint Louis and succeeding Chester beds being of great thickness. Since this seems to be the case, the Greenbrier-Maxville readvance apparently came from the southeast, where continuous deposition was going on. The readvance reached the Iowa-Mississippi region and northern Kentucky in Saint Louis time; but central Ohio, Michigan, and Pennsylvania only in Chester time. This explains the greater thickness of the Greenbrier in Maryland and West Virginia. The retreat of the sea after the temporary advance into Pennsylvania was followed there by the formation of the upper non-marine Mauch Chunk fan, but transgressive movements seem to have continued over the southern Appalachian region.

The Pottsville.—The Pottsville of the Appalachians represents even a better case of non-marine progressive overlap than either of the preceding examples. The series has been worked out in great detail by the Pennsylvania geologists, and the relationships of the beds to each other have been fully discussed by Stevenson,* and, with special reference to the overlap shown by them, by David White.†

One of the pronounced characteristics of the Pottsville is the well known abundance of conglomerates and coarse cross-bedded sandstones. Coal beds and layers of coal plants are common, but marine fossils are rarely found. As has been convincingly demonstrated by Stevenson and David White, the lowest beds of the series—that is, the Pocahontas division—is found only in two areas, and those the most easterly of the series. The first is in the type region of central eastern Pennsylvania, and the other is in southwestern West Virginia and adjoining Virginia. The next higher series, the Raleigh-Bon Air (middle Pottsville), is especially well developed in the southern Appalachians, where it extends through Alabama, eastern Tennessee, Kentucky, and West Virginia. In eastern

* Stevenson: Loc. cit.
† David White: Bull. Geol. Soc. Am., vol. 15, 1904, pp. 267-282.

Pennsylvania the overlap was not very great at this time. The next higher division, the Sharon (Sewell), extended into western Ohio and northwestern Pennsylvania, while the higher beds, the post-Sharon, extended still farther. The following diagrams, copied from David White's papers, show these relationships:



FIGURES 16 I-III.—*Relations of Pocahontas (A), Raleigh-Bon Air (B), Sewell (C), and post-Sharon (D), interpreted as overlapping marine series (according to White).*

White assumes that this transgression was that of a water body transgressing northwestward, and he so labels it. At the same time he recognizes the fact that most of the formations are either conglomerates or coarse sands, and that these various clastics rest in most cases directly on marine limestones or shales. He further recognizes erosion in this region preceding the advent of the Pottsville sediments.

The material of the Pottsville beds shows that they were derived from disintegrating crystalline material. Their coarser and more undecomposed character in the Appalachian region indicates this to have been the source of the material. The utter want in the northwestern region of any area which could have supplied this material makes this conclusion unassailable; for, as has already been stated, the successive beds lie on either marine limestones or shales or on finer non-marine sediments. *These must have constituted the shore at successive periods of transgression* if a Pottsville sea transgressed northwestward, and they should have constituted the source of the material of the Pottsville beds. Such is not the case, as is well known; for the pebbles of the conglomerate are quartz pebbles and the sand is composed chiefly of quartz grains.

We are, then, compelled to consider the crystallines of the Appalachians as the source of the material of these beds. These beds, therefore, overlap *away from the source of supply,* and hence they can not, by any manner of reasoning, be referred to marine or even lake deposits. To refer them to either is to ignore fundamental principles of deposition; yet all or nearly all writers have thus referred them in the past.

A significant fact in connection with the recognition of these beds as river deposits is the remarkable rounding of all the pebbles of the conglomerates. This rounding explains their removal so far from their place of origin, for perfectly round pebbles can be rolled hundreds of miles by streams. It also shows that they have been subject to an enormous

amount of river wear. Of course, the accumulation of these pebbles is the result of continued selection by the rivers of the most rounded pebbles. Since such rounding implies, as above stated, a very long period of river wear, it is not surprising that only quartz pebbles survived the ordeal. Pebbles of more destructible material were ground to sand or decomposed during the process. Thus the remarkable purity and roundness of the quartz pebbles of these conglomerates, so entirely inexplicable on the hypothesis of a transgressing sea, is exactly what might be expected in the case of extensively transported river material.

Since the latest Pottsville beds are overlapped by the Kanawha in northern Ohio, it is more than probable that the Pottsville is entirely absent in Michigan and other western areas, except where represented by equivalent marine strata. Thus the Saginaw formation of Michigan and the Mansfield of Indiana and the Mississippi valley is most certainly post-

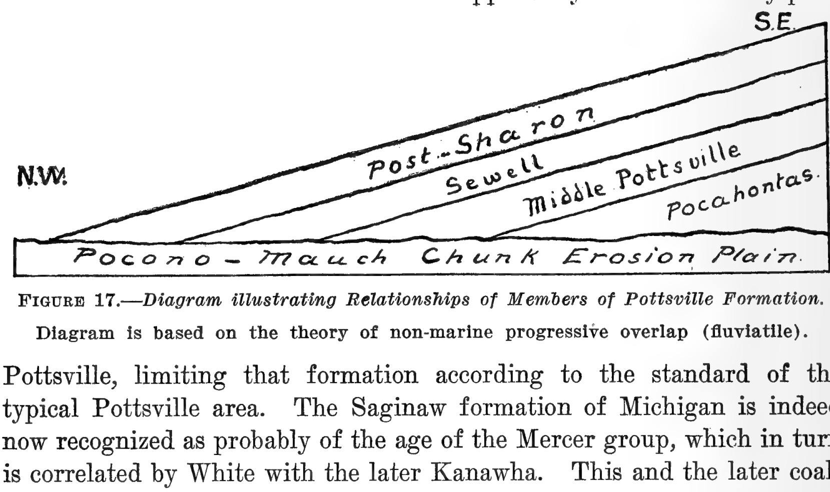


FIGURE 17.—*Diagram illustrating Relationships of Members of Pottsville Formation.* Diagram is based on the theory of non-marine progressive overlap (fluviatile).

Pottsville, limiting that formation according to the standard of the typical Pottsville area. The Saginaw formation of Michigan is indeed now recognized as probably of the age of the Mercer group, which in turn is correlated by White with the later Kanawha. This and the later coal-bearing beds of eastern United States also show evidence of non-marine progressive overlap. They appear to be the remnants of one or more series of fans built out from the Appalachian highlands by streams flowing northwestward, the later members of each fan overlapping the earlier ones of the same series.

Other examples.—Non-marine series, overlapping away from the source of supply, and therefore of fluviatile origin, are to be found in other formations of North America. Among them may be mentioned the Upper Silurics of the Appalachians, the Laramie, and the non-marine Tertiaries of the Great Plains region. The Potomac and Newark formations will probably also show this type of structure when they are studied in greater detail. Wherever it is found, the fluviatile origin of the strata involved is established by it beyond contravention.

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INTERDEPENDENT EVOLUTION OF OASES AND CIVILIZATIONS*

PRESIDENTIAL ADDRESS BY RAPHAEL PUMPELLY

(Read before the Society December 27, 1906)

CONTENTS

Physical Development of central Asia

The beginnings of central Asia, as part of the Great continent, lie far back in the Tertiary period, during a time when mother Earth was in travail, giving birth to her last-born, the new order of continental and organic forms. In the throes of the contracting terrestrial crust there had been slowly born great mountain masses, ranges whose ice-capped giants now mark the boundary between north and south, extending half way round the earth, through the Pyrenees, Caucasus, and Himalayas to China.

The Eurasian continent was born, but in its infancy a great sea extended from the Atlantic through the Mediterranean to southeastern

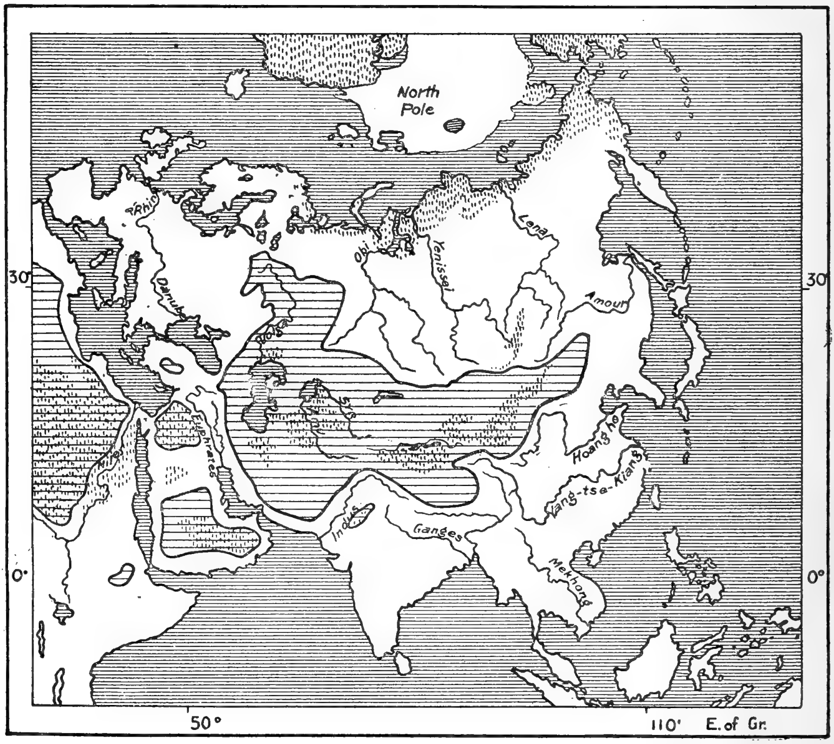
*The subject-matter of this address is the outcome of a careful analysis of some of the results of my expedition of 1904, under the auspices of the Carnegie Institution of Washington.

For the ability to use the pottery of the different cultures as characteristic fossils, I am indebted to the profound knowledge of ceramics of Dr Hubert Schmidt, the archeologist of the expedition.

In the physiography my son, R. W. Pumpelly, who made the surveys and studied minutely the natural records in the shafts, has contributed not only most of the observed data, but also some of the fundamental deductions.

Asia. Later, during the middle Tertiary, this connection was broken, leaving a great interior sea called the Sarmatic, which once extended from Austria to beyond the Aral.

In the progressive development of land and climate, during Pliocene or late Tertiary time, this sea in turn broke up into separate land-locked basins of fresh and brackish water, the deposits and faunæ of which are designated as belonging to the Pontic stage.



Deserts

Tracts with no outlet seaward

FIGURE 1.—*Arid Regions and closed Basins of Asia.*

From Elisée Reclus "The Earth and its Inhabitants."

In these changes we see the evolution of central Asia as an interior region. Differentiated from the periphery of the continent by mountains that intercepted the moisture from the ocean on the south, and otherwise climatically at a disadvantage on account of its geographical relation to the laws of atmospheric circulation, this vast region entered upon an independent course of development.

When this inner continental area ceased to send its waters to the ocean it was predestined to a course of evolution whose progress must inevitably culminate in the desert-waste conditions ruling there today.

Each of the geological periods mentioned had its characteristic land and water organic life, among which were prophetic ancestral forms in the genealogy of the mammals of today.

The cause of this differentiating evolution is as simple as it is fatefully majestic in its progress. The moisture, carried by the high currents of air in their course from the equator to the pole, is largely condensed in rising over the great altitudes of lofty mountain ranges. To the north of the highlands the plains receive but a slight annual precipitation, and this is so distributed in the seasons as to produce the minimum of vegetation in respect to the amount of precipitation received during the year.

Under these conditions a forest growth is impossible and the surface must be more or less grass-covered or bare, according to the amount of effective precipitation, which in turn may perhaps have varied during different periods with a possible varying in height of the intercepting mountains.

Under such conditions the region would vary in character between semi-arid and arid.

Whether semi-arid or arid, the hot air, rising from plains barren of vegetation and heated by the sun of spring and summer, prevents local rainfall, and the residuum of moisture that escaped condensation on the mountains is carried on to the colder regions of the north. It is only during the winter that this residuum is precipitated on the plains as snow, and even this melts away by March, awakening to life a varied desert flora, which in turn vanishes under the burning April sun.

Thus, excepting the relatively ineffective winter snows, the whole of this vast inner continental region receives waters only from the precipitation over the high mountains that separate it from the peripheral zone, and from such mountains as rise sufficiently high within its own area.

Central Asia from the western border of Manchuria to the western end of the Black sea is a series of great and small land-locked basins. From these no water flows to the ocean, excepting that which the Black sea loses through the canyon of the Bosphorus, which was not opened to the Mediterranean until the present geological epoch.

This great land-locked area is divided into two basin systems: one is the higher-lying Gobi on the east, inclosed on the west between the mountain masses of the Kwenlun and Tienshan.

The western system of land-locked basins covers a great part of western Asia. Extending west from the Tienshan ranges, it is limited on the south by the Persian plateau and the Caucasus and on the north by the low Siberian elevation that forms the water divide toward the Arctic ocean. On the west, from a hydrographic, but to a lesser extent from a climatic point of view, this system includes the Black sea, with the areas drained by the Volga, Don and Dneiper (a large part of Russia), and by the lower Danube.

The Persian plateau itself forms an independent high-lying system of arid land-locked basins.

Of this great western system a part near the Caspian sea lies below the level of the ocean. A large part of the whole system is so situated in reference to the barriers that separate it from the oceans that, given a sufficient quantity of water and the closing of the Bosphorus channel, there would be a land-locked sea several hundred feet deep and larger than the Mediterranean. It is potentially a sea, of which the Black sea, Caspian, and Aral remain as three larger residuary bodies of water. This is due to climatic conditions, under which the precipitation over the region, together with the water brought by the streams from without, is offset by the intense evaporation over the heated arid surface.

With a sufficiently long-continued inflow of water in excess of evaporation and a restoration of the barrier at the Bosphorus, the Black sea and the Caspian would coalesce and, after extending to include the Aral, would rise till an overflow should be reached, either into the Mediterranean or into the Arctic ocean, and our potential sea would become a reality.

If, on the other hand, there should exist a sufficiently long-continued condition, in which evaporation should be in excess of inflow of water, then a time would come when, instead of a sea, there would be only a region of barren deserts.

Our basin is, therefore, potentially both a sea and a desert. At present the two controlling factors—water and evaporation—are about in a state of equilibrium.

The existing residuary seas are therefore, in the rising and lowering of their surfaces, gauges recording the cyclical climatic changes as they occur over the great catch-basins that supply them with water.

Of these catch-basins the northern and western ones are the great hydrographic systems of European Russia and the smaller river systems, chiefly of the Caucasus. The rest lie almost wholly in the lofty mountain chains that stretch with increasing height and area as they go eastward to high Asia. The vast masses of snow and ice constantly accumu-

lating on these heights feed perennially the few larger and countless smaller streams that flow toward the central basin region. Without these, Turkestan would be an absolutely desert and practically lifeless region.

I imagine that the general trend of climatic conditions over the central continental area was from the beginning toward aridity. The mountains that separated it from the ocean were of slow growth, and mountains of moderate altitude are compatible with a moderate amount of precipitation over the interior region beyond them. The grassy plains of Mongolia and of our central western states are illustrations of this.

The early condition of Turkestan and northern Persia during much of Pliocene time may well have been one in which at first forests existed, at least on the piedmont hills and plains, while the rest of the region, that was not still occupied by the residuary seas, consisted of broad, grassy steppes extending to Europe and of interior areas of deserts.

Parallel with the growing elevation of the moisture-intercepting mountains progressed the regional desiccation. The progressive effect of this would be continued shrinkage of the water areas, conversion of much of the central plains into deserts, narrowing of the grass-covered zones toward the mountains, and change in the character and extent of the forested areas.

After the Miocene sea had been shut off from the ocean, it dried up, as is shown in the Sarmatic strata by the widespread deposits of gypsum and salts resulting from the evaporation or the saline waters. That the basin was reoccupied more than once by a more or less extensive landlocked sea is shown in successive formations characterized by changes in organic forms and by old beach and water lines.

There is little doubt that these expansions of the water area record the climatic changes that mark the advent and phases of the glacial period. An effect of these changes, which were of mundane extent, was doubtless an increase of precipitation over a larger part of the central region.

In the Glacial period a large part of Russia west of the Ural mountains was covered to a depth of several thousand feet by ice, a large part of which in melting went toward filling the central basin. Our exploration in 1903, as shown in the reports of Professor Davis and Messrs Huntington and R. W. Pumpelly, have proved the existence of several successive glacial epochs in the mountains of high Asia during the glacial period, and that glaciers existed on a greatly extended scale

throughout the mountains bordering the great basin on the south and east.

Each of these epochs of glacial expansion must have had its echo in a corresponding expansion of the water area and in a reaction on the climate of the basin region itself, in the direction of local precipitation and amelioration of the desert conditions.

During the glacial and interglacial phases of the Glacial period there must have existed a continuity of broad and perhaps alternately tundra and grass-covered steppes along the whole length of central Asia into Europe.

The great "Central" basin system resembles the ocean in that it is the sink into which all the solid and dissolved products of the destruction of the surrounding country are brought. In the ocean all such detritus is classified by gravity, wave action, and currents, which distribute the graded material over wide areas. On the dry surface of the desert plains this classification and distribution is begun by the rivers and finished by the winds.

While in the ocean the sand is deposited to become stratified beds of sandstone, and the clays to form ultimately beds of slate, in the arid basin the sand accumulates in moving hills and the finest silts are borne off by the winds to form the remarkable and economically important deposits of loess.

We have seen that the lofty mountains intercept most of the moisture brought by air currents from the ocean, and that the fiery column of air rising from the heated barren plains prevents precipitation except in winter; but there is a zone between the deserts and the mountains on which sufficient moisture falls in spring to nourish the grasses of a semi-arid region. In Mongolia, where the intercepting mountains are low, the zone is broad. In Turkestan it is narrow or in places now almost wanting. During the cold Glacial period it was wide.

I will ask you now to consider this central region as an organic whole.

Imagine yourselves, if you please, looking down over this great expanse and, foreshortening space and the vista back through untold centuries, able to view the successive phases of its life during a short period of geological time.

First, you are in the Glacial period. On the south you see the giant mountains, from the Caucasus to China, covered with snow and, on the higher masses, great domes of ice and far-reaching glaciers.

Far away in the northwest you see the cap of continental ice spread thousands of feet thick over nearly all of European Russia. Between these limits your sight wanders over the blue waters of a sea greater

than the Mediterranean and fed by the larger rivers that flow from the snow and ice capped regions.

You see the rivers building great deltas where they enter the sea, while above these they spread their silts far and wide over the aggrading plains.

Remember that while you look, in *your* time-perspective millenniums are as seconds. Even now the Glacial period has passed and the reaction has begun, and you see the beginning of a general trend toward desolation. The ice-cap is gone from Russia and the great glaciers on the southern mountains are diminishing in extent. Evaporation is now more rapid than inflow of water, and the sea is shrinking and breaking up into smaller basins. With each lapse of thousands of years you see the larger rivers grow smaller, while many of those coming from the southern mountains fail to reach the receding sea. Those great gyrating columns that are coursing the surface of the earth show that the dried silts have become the prey of the winds.

And now, if you will look closer, you will see at their work all the controlling agencies that are the life of the great geographic organism that we call an arid inner-continental region. You observe that the floodplains and deltas and the drying beds of seas are covered with dried silts of clay, sands, and gravels.

The winds are working these over and classifying them according to size of grain. The finest material is easily lifted and carried afar, and it is this that forms those massive yellow clouds that are darkening those plains in their progress, and those gyrating columns—vortices in the heart of the sweeping whirlwind.

Of the coarser silts the winds move only the sands, and these only slowly, along the surface of the plain where you see them, forming great seas of sand waves or dunes, in places more than 100 feet high. These waves progress as each high wind, lifting sand from the windward side, deposits it on the lee side. As the winds vary in direction during the seasons, so does the progress of the dust and of dune waves. But it is an important fact for us that both dust and dunes make an absolute progress during the year in the direction of the predominant winds.

Watch those columns and clouds of dust; as the wind falls, they disappear, settling on the surface to wait to be borne on the wings of the next wind-storm.

Look now toward the grass-covered plains bordering the deserts; no clouds rise from these; on the contrary, the volumes of dust that fall here, fall to remain under the protecting vegetation; the grass is nourished perennially by the dust, and under this reciprocal process the sur-

face rises slowly during the centuries to form great thicknesses of the soil we call loess.

Look back again over the region; while the sand from which was separated the dust you have just seen deposited to form loess lags still scores of miles behind in its advance, you see the grassy plains bordered by a sea of high and older sand dunes. They, too, have been arrested in their overwhelming progress by the slight growth of grasses and plants that are compatible with a soil of sand, under the slight precipitation near the border zone. Both the loess and the dunes grow continually in height.

You have seen a cycle of geological activity quite different from that which takes place on the periphery of a continent where the silts are distributed by ocean currents over great submarine areas.

Here, on the contrary, the waste from the degrading mountains, which was spread by rivers over the plains, is returned by the winds to pile up on the piedmont zone, and this is obviously true not only of the solids, but of the soluble alkaline and earthy salts as well.

All this conforms strictly to Richthofen's theory, that loess is a product of deflation of desert surfaces, wind-borne till it found protection on the grass-covered zone. Here, however, we see that water intervened as an earlier transporting agent, and that evaporation, on the plains, restored to the fine silts the salts that had been leached out. That loess may form without the intervention of water we have seen in the extensive deflation of rocks on the high deserts of the Pamirs.

Let us return to your panorama; it is still that of many thousand years ago, and the grassy steppes across all central Asia teem with herds of wild ruminants and horses and other animals that during early glacial and interglacial time were common to the Eurasian continent.

I will ask you to look, at the same time, toward the edge of the plains. At short intervals you will see streams emerging from the mountains through canyons onto the plain, where they spread out evenly over large fan-shaped deltas that slope radially outward from the apex at the canyon mouth. These are the delta oases, of which I shall have more to say.

Casting your eye along the southern border of the plains, from the Caspian sea eastward you see grassy loess-plains fringing the southern mountains and filling out the great embayments between the spurs of the Tienshan ranges in the east. But everywhere both these plains and the deltas are hemmed in by the sea of dunes.

During your foreshortened time scale your present glance sees the effects of later climatic oscillations. It is perhaps a period of diminish-

ing regional precipitation; the zone of vegetation narrows, the scant protecting plant life disappears from the dunes, and they advance over the edge of the loess belt and encroach also on the shrinking delta-plains. With a period of renewal of precipitation vegetation resumes its former area and the loess deposits expand over the dunes.

The processes which we have reviewed have been operating with fluctuating intensity since Tertiary time.

The maximum of intensity existed probably as a consequence of the Glacial period.

Glacial epochs were accompanied by swollen rivers with broad flood-plains, expansions of the seas with extensive marshes, and by great extent of loess steppes.

During interglacial epochs the conditions were reversed; and after the last Glacial epoch there began the general trend toward the present condition of aridity—a trend that was interrupted by oscillations, in some of which the aridity may have exceeded that of today; a process in which the seas, while responding to the oscillations, have in the main shrunken gradually to the volumes compatible with the present equilibrium between precipitation and evaporation.

Parallel with this progress toward aridity, under the diminished precipitation and lessening to disappearance of the ameliorating climatic reaction of the once expanded water areas, was the shrinkage of the loess zones. The grassy steppes, which had once teemed with life and permitted the distribution of ruminants and the horse across all Asia to Europe, gradually became broken up into disconnected areas by the increased intensity of desert conditions.

The expanding deserts cut off the connection between the faunæ of southern Turkestan and Persia on the one hand and those of Europe on the other, and allowed the evolutions of regional varieties; and there must have been a similar reaction upon the distribution of man.

After this, a continued progress toward extreme aridity advanced the desert sea of sands till its dune waves, rolling ever nearer to the mountain, completely submerged long stretches of the narrowed loess zone between the now restricted deltas at the mouths of mountain streams.

The teeming herds of ruminants and horses disappeared over vast areas, and life was restricted to the mountains and to the borders of the few remaining streams and the deltas.

When this stage had been reached, in early prehistoric time and long before the introduction of irrigation, the condition of southern Turkestan and northern Persia may be summed up as one of deserts relieved only by oases on the deltas at the mouths of streams emerging from the

mountains, or where larger rivers died out on the plains or entered the shrunken seas.

The Kurgans Excavated in 1904

The delta oases have been the home of man from early prehistoric time till now, throughout Turkestan and northern Persia. It was on one of these, at Anau near Askabad, 300 miles east of the Caspian, that I made in 1904 the excavations and physiographic studies, some results of which are the subject of this address. In the center of the delta oasis stand two hills, a half a mile apart, and the ruined city of Anau one mile from both.

These hills, or kurgans, consist of layers, the remains of human occupation—culture strata, we call them—that have accumulated during thousands of years of habitation.

They are the time-wasted, wind-and-water-carved remnants of long-forgotten cities. Together with the neighboring ruined citadel, they represent an almost continuous series of successive cultures whose local beginnings seem to antedate the dynastic remains of Egypt.

My shafts showed that these culture strata extend to a depth of 20, and in some cases to 28, feet below the level of the plain which has grown up around them.

Our excavations showed that the northern kurgan, which is 60 feet high from its base below the plain, is the older, and that the southern kurgan was not started till after the abandonment of the northern one; it has now a height of 72 feet above its base; and after this was abandoned the city of Anau started, and lasted till the middle of the last century, having grown to a height of 38 feet, of which 15 feet are below the level of the plain.

To try to find out why two kurgans, starting thousands of years apart, should have been buried to the same depth, I sank a series of over 20 shafts, both through the heart of the hills and on the plain.

I have time to give only such brief statements of the interesting results obtained from these shafts as bear directly on the subject in hand.

Culture Succession

To aid in this brief description of these ancient sites from an archeological standpoint, I have represented the leading results on the diagram shown in figure 2. There are present six successive cultures of distinct populations, giving a section from the present time down through the historic, the iron and copper stages, into the Stone age.

These are represented in 170 feet of culture strata still remaining out of an original aggregate thickness that has been much diminished by wind and rain.

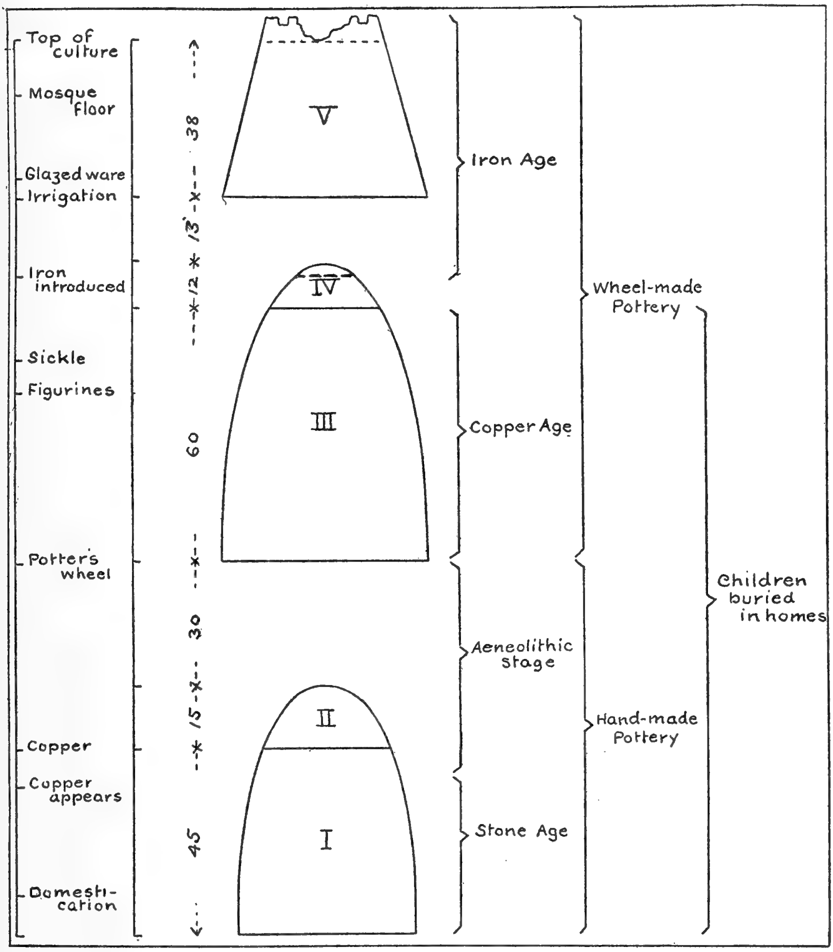


FIGURE 2.—*Diagram of the Successive Cultures at Anan*

I and II, north Kurgan; III and IV, south Kurgan; V, city of Anan.

In the diagram the three sites are represented one above the other, and intervals are left between them to represent the height each kurgan is estimated, as I will show, to have lost in the long lapse of time.

Already the oldest of these cultures appears here with a well developed pottery made by hand and a stock of geometrical designs which they

painted on certain classes of vessels. They had the art of spinning; and they baked, in bottomless bake-oven pots, bread made from material ground on mealing stones. They made knives flaked from flint, but they had no axes, spear heads, nor arrow points of stone, nor yet artificially formed sling-stones. They were hunters, and such weapons as they used must doubtless have been spears or arrows with points hardened in fire or tipped with bone.

In view of the importance that attaches to the question of the origin of our domesticated animals, I collected systematically, foot by foot from the bottom, all the bones of animals found in the older two cultures—that is, in the whole height of the north kurgan—and submitted nearly half a ton of these to Doctor Duerst, comparative anatomist and archeological osteologist at Zürich. He finds that during the growth of the lowest 8 or 10 feet of the kurgan the inhabitants knew only wild animals, and that out of these they domesticated the ox and the sheep, of which latter animal they in the course of many centuries established successively three breeds. He was able to trace the progressive changes in texture of bone substance and in the character of horns during the many centuries of progressive domestication. They appear to have domesticated the horse, too, but they imported an already domesticated pig and goat from Persia.

I will add that of these Doctor Duerst identifies assuredly one of the breeds of sheep and the pig with the domestic "turbary pig" and "turbary sheep" of prehistoric Europe, where the earliest remains of these animals found in the pile dwellings and other sites show that they arrived there already domesticated.

This is, therefore, the first discovery of the origin of domestication, and of the region from which the world derived the greater number of its useful animals.

This people was suddenly supplanted by a new one, with an entirely different pottery, still hand-made, but more developed, and with a different stock of painted ornamental geometric designs.

They had also the art of spinning, and all the indications are that they made their bread in the same way as their predecessors, and used flint knives. With them there appears the camel, probably the Bactrian two-humped variety, and a limited use of pure copper. While they made knives of flint, they, too, had neither axes nor spear or arrow points of stone or metal.

No succeeding civilization occupied this kurgan. The next arrivals started the neighboring settlement, which became the south kurgan,

and which, under their peculiar civilization, lasted enough tens of centuries for their remains to accumulate to a height of 60 feet.

They brought with them the potter's wheel and their own technique in pottery; and they had a full knowledge of the use of copper, and a knowledge of lead, which for some purposes they alloyed with copper. But they did not know bronze. Out of 23 objects analyzed by Professor Gooch, a ring and a small implement contained under 6 per cent of tin; a dagger, 1.58 per cent; another small object, 1.65 per cent. Excepting these four, all the others, including two daggers, two spears, an arrow point, a sickle, and a razor-shaped implement, were without a trace of tin.

All of the three cultures that I have mentioned had in common a remarkable burial custom: they buried children, and only children, under the floors of the houses, in a contracted position.

This people was finally succeeded by one in a low stage of culture, to judge from their coarse hand-made pottery; and they, in turn, were supplanted by a people who brought in the use of iron and a different pottery.

Neither these nor the barbarians who immediately preceded them buried their children in the houses. *The old order of related peoples and cultures was gone, and one showing wide connections was established.*

After this iron culture had left the south kurgan, the city of Anau was founded, and a modern system of artificial irrigation was introduced soon after the beginning of our era.

Relation of the Cultures to Their Environment

It is to the relation existing between these cultures and their environment that I beg now to call your attention.

You have seen how, with the slow trend of climatic change toward aridity, life-sustaining areas became gradually restricted to the desert-bound delta oases at the mouths of streams issuing from the mountains. I will now describe the manner of growth of these deltas and the relation of this growth to that of the culture strata, as we call the accumulated layers of the debris left by successive generations and by superimposed civilizations.

The first information obtained in this direction was from the shafts sunk at and near the south kurgan and shown on figure 2. We were fortunate in finding in these the data for calculating the relative rates

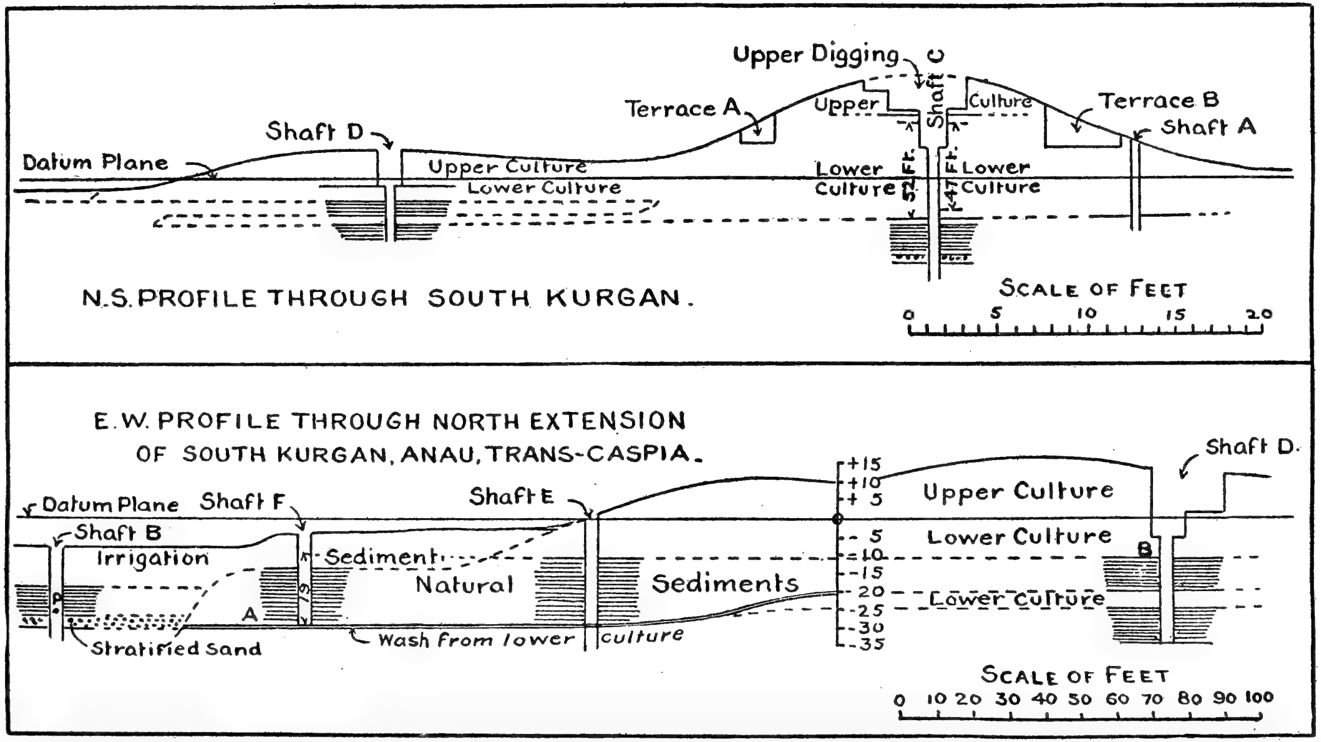


FIGURE 3.—*Sections through the South Kurgan.*

Reduced from the Survey by R. W. Pumpelly.

of growth of the sediments in aggrading the delta on the one hand and of the culture strata on the other.

By referring to the annexed profiles through the south kurgan you will see that a low plateau extends out from the main and high part of the kurgan. Now, while shaft C, sunk to the bottom through the heart of the high part, passes uninterruptedly through culture strata, shaft D, in the projecting plateau, after sinking through culture strata, enters natural sediments, below which it passes again through culture strata till it finds the base of culture at the same level as under the main body of the kurgan in shaft C.

As we recognize geological horizons by their characteristic fossils, so here we recognize the cultures to which these strata belong by the very characteristic pottery in which they abound. We find interbedded in the natural sediments in shafts E and F a layer of wash containing fragments from the same lower culture that was cut in shaft D. After the deposition of this pottery the natural sediments grew 19 feet in height, submerging the settlement and rising to the level at which it is covered by culture strata in shaft D, which is 16 feet below the beginning of the pure iron culture.

Now, the evidence in shaft C is that the main body of the kurgan grew uninterruptedly from its base 52 feet, to reach there the level, 16 feet below pure iron culture. If we assume that these 19 feet of sediments began to grow contemporaneously with the founding of the kurgan, the relative rates of growth would be $52/19 = 1:2.733$.

It is possible, however, that the whole thickness of the 7 feet of submerged culture strata contributed to the layer of "wash" with pottery in shafts E and F; therefore, if we subtract these lowest 7 feet of culture strata shown in shaft D from the 52 feet in the main body of the kurgan, we have the rates: $45/19 = 2.368$; say, 2.37. But, everything considered, it would seem proper to take $1:2.5$; that is, 1 natural sediments to 2.5 culture strata as the relative rates of growth.

This ratio being obtained from the parallel accumulations of a considerable period of time has, as we shall see later, for our purpose both an archeological and geological value.

After the sediments had reached the height shown in shaft D, there came a change, and this part of the plain was dissected; for, a little farther eastward in shaft B, we find a new series of sediments marking a renewed aggrading.

Now, when this new growth had reached the level indicated by a dot below the letter P, in shaft B, it received fragments of the pottery pecu-

liarly characteristic of the uppermost or iron culture of the kurgan; and from this level it continued to grow upward a further 7 feet, after which irrigation was introduced. Now we have archeological and stratigraphical evidence that the introduction of artificial irrigation was about contemporaneous with the founding of the city of Anau and the abandonment of the south kurgan.

Our ratio, 1 to 2.5, is equivalent to a growth of 17.5 feet of culture strata between the time of deposition of the iron-culture pottery in shaft B and the apparently contemporaneous ending of the life of this culture and the beginning of irrigation, while there are only 4 feet of iron culture now standing on the top of the kurgan. The great deformation that this hill has suffered is evidence that it has lost a considerable amount of its original height, and it is likely that the difference between the 17.5 feet of iron culture required by our ratio and the 4 feet now standing is a proximate measure of that wastage. I have therefore, in the column of cultures, added this 13½ feet to the present thickness of culture strata of the south kurgan; and since the time of abandonment of the north kurgan is separated from us by nearly three times as many centuries as that of the south kurgan, I have added to it 30 feet to represent the culture strata wasted by wind and rain.

Let us turn now to the shafts at the north kurgan. Here in shaft I, 200 feet west of the kurgan, we found a wall and hearths and lower-culture pottery at a depth 8 feet deeper than the base of culture in the kurgan. The conditions showed that the settlement was started on the side of a valley which had dissected the delta-plain. Several hundred feet farther west, in shaft II, we could trace the progress of refilling of the valley, for, at the same level as the deep culture in shaft I, we found here pottery of the lower culture. This pottery characterized the upward growth of the strata during 8 feet. At this level the association of upper-culture pottery, charcoal and bones, as well as their conditions, indicate that the aggrading had ceased.

The sediments above this pottery seem to belong to the latter aggrading, which submerged the early culture at the south kurgan.

Change-producing Agencies

Let us now consider the agencies that have been active in these processes of cutting down and rebuilding. They form one of the most interesting illustrations of the law of compensation in the grand cyclical action of forces that have modeled the relief of the surface of our planet.

A great mountain range, several hundred miles long, forms the sharply defined southern edge of the desert plains of eastern central Asia. It rises everywhere abruptly from this plain to a height of from 5,000 to 10,000 feet, and its height is sufficiently great to cause it to receive abundant precipitation and a heavy covering of winter snows.

Within this mountain system the trunk valleys, after following a longitudinal course, turn sharply and, cutting through the border range and piedmont hills, debouch their waters onto the plains.

The mountain masses, lacking the protection of a heavy forest growth, are subjected to rapid disintegration and decay, and the resulting detritus is carried by the torrential rivers down to the plains.

In a coastal region these waters would flow onward to the ocean and the silts they had brought from the mountain would ultimately complete the same course, to be deposited at the mouth of the river, to form there a submarine delta; but in an arid "central" region, such as is Turkestan, the conditions are different. The precipitation is confined to the mountains, and on leaving these the rivers immediately spread out in a region of rapid evaporation, where there is no compensating rainfall, for the valley ends at the mouth of the mountain gorge.

Thus all the coarse and fine materials brought by the torrential rivers from far and near in the mountains are deposited within a zone along the edge of the plain at the base of the Kopet range. The rock-mass of the mountains is therefore being continually removed and loaded onto this long zone.

Now two connected phenomena result from this process: on the one hand, the zone of deposition is continually and proportionately sinking under the increasing load, and on the other hand the mountains are continually rising to maintain their height.

The strain established in the rigid crust between the sinking zone of deposition and the rising mountain range finds relief in the development of fractures along the range, as well as others which permit a differential uplifting of great block-masses. The evidence of this compensatory maintenance of hydrostatic equilibrium is strikingly recorded both in the Kopet range and in the zone of deposition. All along the range the lines of fracturing are visible on a large scale in well developed faultings, and the border of the alluvial plain is bent sharply upward, having been dragged up by the rising mountains.

Deep longitudinal valleys are carved by erosion along the lines of weakness offered by these fault-planes. On the mountainward side of the valley rise the older rocks of the range, while on the other is a steep

wall, formed often by the basset edges of beds of conglomerate which are the up-bent representatives, near the mountains, of the alluvial strata of the plains.

On the other hand, the sinking of the zone of deposition is proved in the deep artesian well southeast of Askabad. This boring remained to a depth of over 2,200 feet in a pure delta formation, and was still in this when boring was stopped, at a depth of about 1,400 feet below the level of the ocean.

The delta is broadly divided into three zones of deposition: That of quickly dropped coarse detritus at the apex; the main body of the delta, the rapidly descending broad surface of which receives sediments from the overflow during the floods; and the outer, more or less flat, border, which receives both the finest material and any of the silts that escape with the water that in flood-time finds its way, to be lost beyond on the bordering plain.

This bordering zone belongs not only to the delta, but to the desert as well; and it is here that is waged the eternal struggle between the desert, with its breath of fire and its overwhelming sea of sand on the one hand and the life-bringing waters on the other.

The sands from the desert encircle the whole delta with a wall of great wave-like dunes. That they do not bury it is due chiefly to the slight growth on them of grasses that arrest the action of the wind, while the smaller amount of sand that reaches the delta is distributed by the aggrading waters.

The delta streams maintain channels through these dunes, by which the excess waters of the floods find their way, to spread out among dune-locked depressions, where on evaporating they leave their clay sediments to form the takyrs or adobe flats.

The continued process of aggrading on the three zones of the delta is, therefore, of a complex nature and dependent on varying factors: At the apex, there remains the greater part of the coarsest material, boulders, cobble, gravel, and coarse sand; the middle zone receives in overflow much of the finer silts, while the rest of the finest silts accumulate on the lowest slopes as far as the dune-barrier; and here, too, as well as beyond in the dune-locked depressions, are deposited the coarse and fine sediments rolled along its bottom or carried in suspension by the stream.

Parallel with the contribution from the mountains is that from the boundless desert on the north. As we have seen, a part of the sand from the desert is distributed and assimilated by the living delta. Besides this the desert whirlwinds come laden with fine dust, and where this falls

on the delta it remains caught in the vegetation and it, too, enters as a loess constituent into the delta structure.

Of the two essential factors—mountain-rising and precipitation—we may, I think, take the rising of the mountains to average a constancy adequate to the maintenance of a relatively constant grade. On the other hand, we will probably be right in dealing with considerable periods of time, if we assume that precipitation is a factor of more varying intensity. It is evident that, other things remaining equal, the amount of detritus brought from the mountains will be proportionate to the amount of precipitation to supply the volume of water needed to move it.

After this detritus emerges from the mountains, the manner in which it builds up the delta depends largely on the relation between the secularly maintained volume of water and the established grade.

The tilting of the edge of the plain favors erosive action and deepening of the channels of

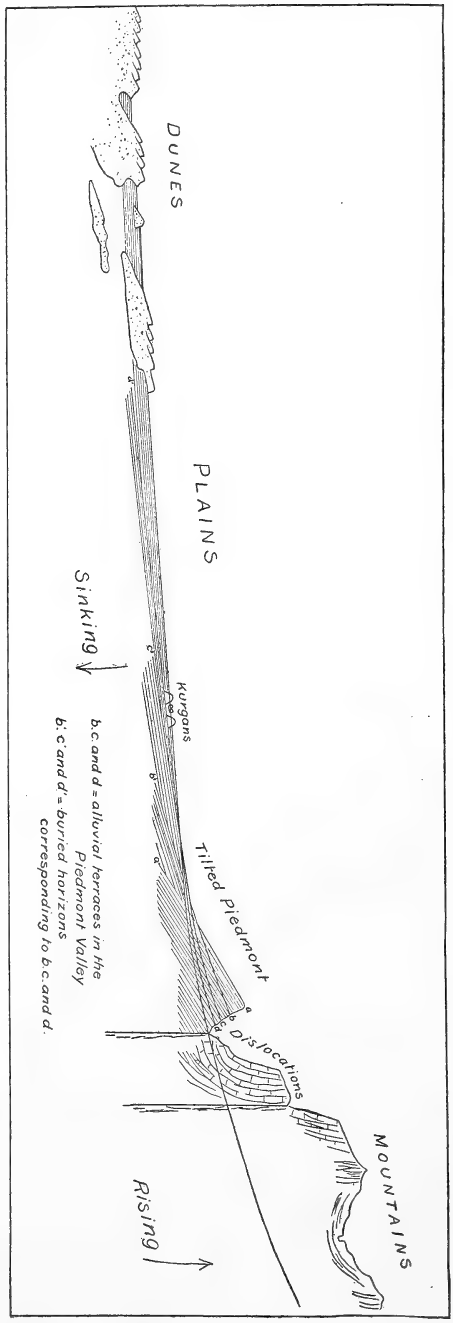


FIGURE 4.—*Partly idealized Section through the Oasis of Anan.* Illustrating the effect of tilting along the margin of the aggrading planes of Turkestan. By R. W. Pumpelly.

watercourses across the deltas. Such a channel having been established across a delta, all the material that is not dropped on account of its coarseness at the apex near the mountain is carried onward. Where the floods can overflow the banks, they deposit silts on the general surface; but the greater part of the detritus carried goes to the gently inclined and dune-barred foot-plain of the delta, where it spreads out, forming an alluvial plain around the lower slope of the fan. We may call the upper edge of this aggrading plain the grade-contour line of alluvial shore. The mouth of the valley will always be at this shoreline and move with it upstream or downstream.

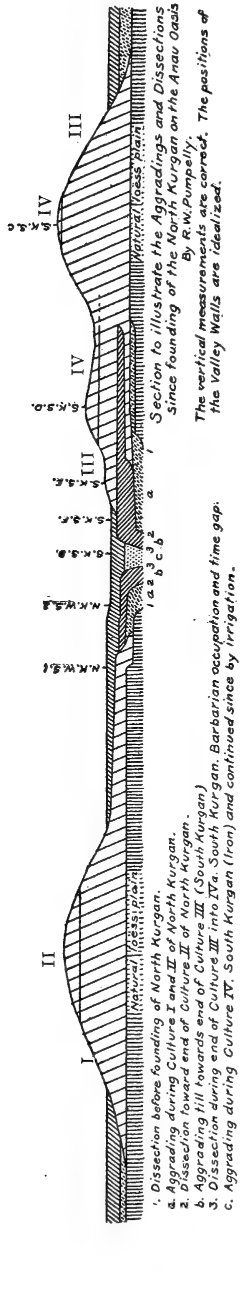


FIGURE 5.—*Section to illustrate the Aggradings and Dissections since the Founding of the North Kurgan at Anau*

I. First culture. II. Second culture. III. Third culture. IV. Fourty culture.

Border-tilting remaining the same, this alluvial shoreline moves up and down along the delta slope, according to the fluctuations in precipitation. The greater the volume of water and of its silts, the more rapidly will the alluvial plain be aggraded, its shore be moved up the delta-slope, and the tilted piedmont valley be obliterated in its lower stretch.

A sufficiently long continuance of these conditions will aggrade the whole delta, covering it to its apex with a shell of alluvial strata, and the valley will be wholly obliterated; the surface of the delta will now become the floodplain of the stream and the aggrading will now occur over the whole surface from the apex downward.

On the other hand, with a sufficient diminution of precipitation and of inbrought silts, mountain-rising remaining constant, the stream, untrammeled by excessive load, will again work at cutting a channel; agradation will be at cutting a channel; aggradation will be channel mouth, move to the foot-plain or beyond, among the dune-locked basins of the desert; aggrading will be continuous below the zone of oscillation of the alluvial shoreline.

Let us now apply these principles to an interpretation of the facts observed in the shafts at Anau in their bearing on the history of the prehistoric settlements.

The cutting down of the valleys, observed there would represent periods of lesser precipitation, and the refilling would mark periods of increased precipitation.

Time			Physiography						Archaeology
			Mountains		Dislocation Zone Border of Plains		Plains		
Pre Glacial			Quiet	Old	Quiet				
Quaternary Glacial Period differentially recorded, with local epochs in mountain valleys according to uplift			Slow rising, differentially in blocks	Young Rapid dissection to deep valleys	Active dislocation	Tilting Border, buried, in general rapid	Slow sinking as a whole	Aggrading rapidly with grass steppes over large areas, stationary sand hills and loess	Evolution of quaternary life over the steppes of Asia Primitive Man.
Post Glacial	Extreme recession	Reaction to extra dry climate		Slow dissection		Rising of the tilting border to form a dry Piedmont transversely dissected by valleys.		Aggradation slow Desert steppes Moving sand.	
	Oscillating Advance	Partial recovery of precipitation		Less slow dissection		Valley fills to—(28) and continue filling to—(20)		Grass	Aeneolithic Man Founds North Kurgan
		Dry		Slow dissection		Valley reexcavated to below —(35)		Desert	Culture gap
		Recovery		Less slow dissection		Valley filled again to —(12)		Grass	Foundation and growth of South Kurgan Barbarian
		Dry		Slow dissection		Valley reexcavated		Desert	
		Recovery		Less slow dissection		Valley fills to— (15) and then		Grass	Iron
		Dry				overflow with irrigation		Desert	Anau

FIGURE 6.—*Tentative Correlation of Human and Physical Evente during Quaternary and Recent Time.*

The information obtained in the shafts is brought together in figure 5, in which the essential facts are represented correctly in the vertical scale, while in the positions of the valley walls are necessarily idealized.

During a dry period preceding the founding of the north kurgan, a valley had been cut in the delta-plain, the surface of which dated from loess-forming time.

Then came a period of increased precipitation, during which the valley was refilling during the life of the oldest culture and into that of the second.

During part of the second culture—the latter part of the life of the north kurgan—there recurred a dry period during which the valley was reexcavated. When, under renewed precipitation, it began to refill again, the south kurgan was started on the west side of the valley, on the orignal loess-plain. This growth of sediments continued till it rose higher than the previous aggrading, overflowing not only the terrace of this and the general plain, but also a part of the earlier culture of the growing south kurgan; and it continued to grow until the flourishing period of the life of this kurgan was drawing to a close, at a height of 52 feet above its base.

Then followed again a change to dryness, causing the reexcavation of the valley and lasting through the life of the supposed barbarian occupation.

Again a reverse change caused the refilling (shaft B) that followed, which lasted till the introduction of irrigation, and this period of refilling coincided with the life of the Iron culture.

The coincidence is thus very marked between the founding and growth of cultures and the conditions of precipitation that permitted the aggrading of this part of the delta; and equally well marked is the relation between the dry periods and the disappearance of cultures.

In the accompanying table, figure 6, R. W. Pumpelly has attempted to correlate the march of human and physical events during Quarternary and recent time.

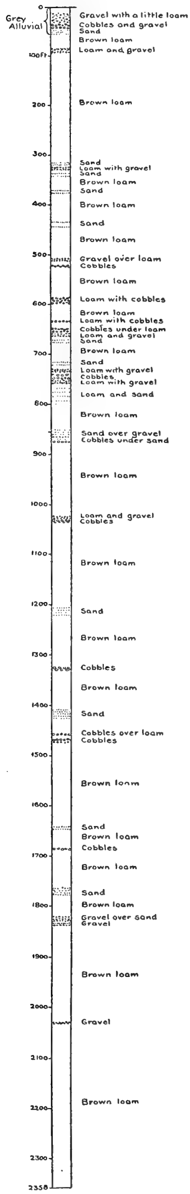


FIGURE 7.—*Artesinn Well at Askabad.* (From the record of boring given in J. Walther's "Gesetz des Wustenbildung.)

The record in the Askabad well (figure 7) is very interesting, for it gives a section extending 2,300 feet down in the zone of deposition and depression. Below the upper 60 feet, with the exception of layers of coarse material aggregating less than one-tenth of the volume, it consists uniformly of a

brown loam, which indicates clearly that loess-dust enters into it as an important constituent. Of the upper 60 feet, 50 consist of more or less coarse material in which the brown loam is absent.

The conditions that permitted the forming of these great thicknesses of brown loam were apparently those belonging with a greater amount of both general and local precipitation. They presuppose, I think, a degree of moisture that does not now obtain, under the influence of which there was a perennial growth of grass sufficient to allow the growth of intimately mixed alluvial silts and loess-dust.

Of the upper 60 feet of this column, 50 feet consist of more or less coarse material without brown loam, and I imagine that the top of the brown loam at —60 feet in the well is proximately contemporaneous with the similar material under the north and south kurgans, and that its greater depth may roughly correspond to the depth to which degradation extended before the refilling of the valley occurred, during which the north kurgan was started.

The absence of the brown loess-dust constituent, both from the upper 60 feet in the well and in the sediments deposited at Anau after the starting of the north kurgan, points, I think, to a diminished precipitation over the piedmont zone; that is, diminished sufficiently to cause a deficiency in the growth of grass required to retain the loess-dust.

When we compare, further, the upper 60 feet in the well with the whole of the column below, we see that there is evidence of a great change from a long-continued different condition; and when we consider together the apparent decrease in vegetation indicated by the absence of the loess constituent, and the evidences, both geographical and archeological, of regional desiccation, the change would seem clearly to have been toward aridity. The successive degradation and rebuildings recorded in our shafts show that this period was one of fluctuating climate—a time in which the periods of greater precipitation affected the mountain regions without causing local rainfall, after winter, on the zone of deposition.

The time needed for the accumulation of the observed 2,300 feet of sediments in the Askabad well can be estimated only in geological chronology. It doubtless extends well back in the Pleistocene period, and it is not unlikely that the conditions shown in frequent recurrences of coarse cobble-beds between the depths of 500 and 900 feet mark the last great glacial advance.

Looking on the loess-forming condition shown below —60 feet as typical of the piedmont plains of southern Turkestan generally and

probably of northern Persia as well, we see correspondence with the conditions that permitted the existence of the herds of ruminants and horses that in Pleistocene time ranged from Mongolia to southeastern Europe; and that these animals existed in a wild state at Anau at the time when the north kurgan was settled is proved by Doctor Duerst's study of the bones collected during our excavations.

Introduction of Irrigation

If we look at the present climatic conditions ruling throughout Turkestan, we find that irrigation is now almost everywhere essential. The only exceptions are the high valleys and the piedmont borders of the more lofty ranges.

At a few points, as near Samarkand, grain is planted on the mere chance of there coming once in two or three years enough rain to mature a scanty crop; but along the piedmont plain of the Kopet range there is no local precipitation after March.

The arid extreme of the climatic fluctuations, which coincided with the disappearance of the different cultures of the kurgans and seem to have caused these interruptions, were very probably less dry than is now the case, but they were doubtless sufficiently severe to render the previously practiced system of agriculture useless for the maintenance of population and of domestic animals.

Not until the introduction of the artificial distribution of water was it possible thenceforth to maintain a continuity of civilized life.

The introduction of irrigation reversed the order of the delta-building processes. By bringing all the water under control through the season in which it carries sediments and distributing it evenly over the delta, the aggrading shoreline was kept back at the apex, instead of receding toward the desert, and the delta was continually built up over its whole extent. That this has been the case ever since irrigation began is shown by the fact that since the first layers of irrigation sediments were deposited over the old channel shown in shaft B, there has been no recurrence of dissection.

Had irrigation not come to the rescue, the aggrading shoreline would have receded desertward and the prolonging channels would have carried the sediments onward to form barren takyrs, or mud-flats, on the dune-covered plain.

Since the greater part of the fine sediments brought from the mountains is now retained on the delta, the rate of growth of the irrigation

formation is more rapid than was that of the natural sediments observed in the shafts. At present our only way of estimating this rate is by comparison with that of the accumulation of culture strata. Both the city of Anau and the irrigation formation started on the natural surface of the delta; and, while in the city the culture strata have grown to a height of 38 feet, the irrigation formation has risen on either side to a thickness of 15 feet, which would give a ratio of 1 of irrigation to about 2.5 of the culture strata of the city of Anau, which accumulated more rapidly than those of the kurgans.

CHRONOLOGY

The greatest interest centers, naturally, in the problem of the age of these different cultures, and in their relation to the origin of Western civilizations, if any relations may be shown to exist.

The wide geographical separation between Anau and the fields of Western cultures and the paucity of objects found by us that recall in a definite manner similarities to objects of external civilizations surround the subject with the greatest obstacles.

Any treatment in the direction of proximate dating of any one of the cultures of Anau or advancing a general chronological scheme can be at the best only tentative and can serve only as a working hypothesis.

Such a working hypothesis has gradually formed itself in my mind and is developed in the following pages.

To begin with, I assume—

First, that distinctive pottery, peculiar to a culture throughout our successively superimposed earth layers, is evidence of corresponding continuity of that culture.

Second, that since it is a fact that throughout the lives of our sites at Anau the towns were built only of air-dried bricks, the secular rate of growth of culture strata can be taken as proximatively uniform.

Third, that two separate sites, whose cultures are characterized by entirely different and peculiar potteries, can not exist contemporaneously for centuries in close proximity to each other without such an interchange of pottery as would come to light during the excavation.

This is applying to archeology the rules of geological reasoning.

We know the thickness of the strata of each of the cultures of the three neighboring sites and we know the aggregate existing thickness of the cultures of each of the sites.

If we take the duration of each culture to be proportionate to the thickness of its accumulated strata, the duration of the entire series will

be represented by the aggregate existing thickness of all the strata plus any time-gaps between different cultures and minus any overlaps of the cultures of the neighboring sites.

In figure 2 I have arranged in one column all the cultures of the two kurgans and the city. In doing this I have represented the two time-gaps already mentioned by the equivalents in culture growth, obtained by using the ratio of 1 sediments to 2.5 culture strata, as already mentioned.

Having established in the column the deduced aggregate thickness of the culture strata, the next step is to find means of determining the secular rate of growth. This would be a relatively simple matter if our column represented culture sites on the Mediterranean, for in that case there could not fail to be many objects scattered through it that could be easily dated in the light of Western archeology.

In remote Transcaspia it is different. The evidence must, in the first line of reasoning, be internal, and in the present state of our work we have few data of approximate value.

In the shafts sunk in the city of Anau there was found glazed pottery continually down to a level of 5 feet above the bottom of culture. Now no authenticated finds of this ware had occurred in the kurgans, excepting in the surface debris of the uppermost strata of the south kurgan, where they might owe their presence to having been left on the former surface at any much later time.

In the main part of the ruined city of Ghiaur Kala, in Old Merv, fragments of glazed pottery were found by us down to a depth of 20½ feet, where they were associated with Sassanide coins of the third century A. D., and below which depth they were not found.

On the strength of this evidence, glazed pottery would seem to have been introduced into Merv not earlier than the third century A. D.; and since, in so far as the evidence of the three shafts in Anau city goes, it first appears there at 5 feet above the bottom of culture, we may assume that its introduction into Anau, which was also under Persian rule, was no earlier.

Its appearance at Anau is accompanied by a change in the ordinary pottery, slightly glazed light greenish ware partially superseding the hard-baked red ware of the lower five feet.

It would seem proper to ascribe these innovations to some important historical event. Now the mullahs told me that Anau was fortified by Nu-shirvan (Chosroes I), whose reign, 531–579 A. D., was the most brilliant period of Sassanian rule. In 557 he made his campaign against the Hephtalites (White Huns) and strengthened his outposts against the

attacks of these nomads of the northeastern plains, and it was probably at this time that he fortified Anau.

I think we shall be on the safe side in dating the introduction of glazed ware in the middle of the sixth century A. D., and in assuming that it was introduced into Persia from its home in Mesopotamia.

There are 33 feet of culture strata overlying the lowest appearance of this ware, and these ceased to accumulate in the middle of the nineteenth century A. D. This would give a rate of 2½ feet per century. That this is not making the rate unduly slow appears from another comparison. The superb mosque at Anau was built in 1444, as stated in the Kufic inscription of its façade. Its floor stands 9 feet lower than the top of the culture strata of the city, which would give a rate of 2¼ feet per century. If we apply the rate of 2½ feet to the whole of the 38 feet, we obtain the middle of the fourth century A. D. for the date of the founding of the city.

The culture strata of the city are of very loose texture; those of the upper, or iron, stage of the south kurgan are considerably less so, while the rest of the south kurgan and all of the north kurgan are very closely compacted. I have for this reason taken a rate of 2¼ feet per century for the period between the top of the copper culture and the founding of the city of Anau and 2 feet for the rate from the end of the copper stage of the south kurgan back to the founding of the north kurgan.

Using these rates, we may establish tentatively the following approximate dating of the essential events:

Founding of Anau	about 370 A. D.
Beginning of Iron culture	in fourth century B. C.
Founding of south kurgan and introduction of the potter's wheel	about 3750 B. C.
Base of upper (aeneolithic) culture of the north kurgan	about 6000 B. C.
First domestication of animals, beginning with the long-horned ox out of *Bos namadicus*	about 8000 B. C.
Founding of north kurgan	about 8250 B. C.

The deduction that the plain below the alluvial shoreline has aggraded at least 65 feet during the past 10,000 years has an important bearing on the limitations of archeological discoveries, not only in Turkestan, but also in all aggrading regions of a similar character.

It is evident that within the zone of continuous aggradation any sites older than the north kurgan must be buried out of sight unless they had been occupied long enough to rise to a height of at least 65 feet.

It will be interesting also to make a tentative application of the chronological data given in the tables to the strata of alluvial growth penetrated in the Askabad well.

The rate of growth of the delta alluvium is 0.8 feet per century as compared with culture strata at 2 feet per century.

An inspection of the record of the boring reproduced on figure 6 will show that between the depths of 500 feet and 1,680 feet the strata of sediments coarser than silts are of the coarsest kinds—large cobble—the long interval between 500 feet and 1,680 feet differing in this respect wholly from the rest of the column, both above and below.

There can be little question, I think, that the extremely coarse character of these beds and the frequency of their occurrence in this part of the column indicate for this interval a correspondingly long period of increased precipitation, during which the swollen streams were enabled to carry the coarsest constituents of their load farther down their channels, while lateral overflow spread much of the finer silts over the delta-surface.

It is likely that this part of the column records some of the phases of the Glacial period. It is also possible that the sediments between 320 and 1,820 feet grew more rapidly than those of the rest of the column, and that our deduced ratios are applicable only to the upper 320 feet, or to the growth of the last 40,000 years.

Turkestan and Irania, a Region of Independent Ethnic and Cultural Evolution under Isolation, dating from Preglacial or Interglacial Time

In considering the observed data of the earliest of the Anau cultures in their ethnographic relations, one must be struck by a singular fact: *They had none of the usual weapons of offense and defense;* the cores from which they made the abundant flint knives arouse our wonderment at the absence of the *arrow-points, spear-heads, and axes* found in almost all advanced Stone Age and neolithic settlements, as well as of maces and artificially formed sling-stones. Now axes, spear-points, and arrow-points of stone are, throughout the rest of the world, everywhere abundant where primitive man has existed, and in the improvement in the manner of their fashioning they serve to mark off the long stages in the slow development of primitive human culture.

The evolution of these implements from the almost natural shape to highly finished forms, specialized for different uses, was exceedingly slow. This has been proved at several points in Europe, where they have been found in strata of different epochs of the Glacial period and

intimately associated with undoubtedly contemporaneous animals of those epochs, and in all cases the progress in time is paralleled by the improvement in workmanship.

So true is this considered to be, that in studying these successive stages, glacial and interglacial, in Europe, of the Glacial period, the evolution of forms and of workmanship in the stone implements, when such are found, is only second in value to the bones of those animals with which the implements are associated and which mark the long oscillation between subtropical and arctic climates.

The early use of stone as a tool and the slowly developing inventive faculty at last rendered possible the manufacture of finely formed axes and spear and arrow points. These were acquisitions that stood casually and first in human development, in the same order with the discovery of the use of metals, powder, and steam.

It is not conceivable that a people who had once possessed this acquisition and had used axes and arrow-points and spear-points of stone could have lost the advantage these offered. This would be still more remarkable in the case of our Anauli, who, though settled in communities, still hunted wild animals and who had quartzite close at hand, as well as the flint of which are found the knives in such abundance and the cores from which they were flaked.

I see no way of accounting for the absence of these forms of implements and weapons except on the hypothesis that the ancestors of this people had become absolutely isolated from the rest of mankind at a period so remote as to be before the invention of these forms and perhaps even before the use of stone as a tool.

And they must have remained without contact with peoples among whom these implements and weapons were in use.

The next and necessary deduction under this hypothesis is that the whole of their culture is autochtonous, in the sense that it received no impulses from outside the people or circle of peoples so isolated.

It presupposes an early separation of a great inner continental region from the rest of the inhabited world.

I imagine that the cause of this separation is to be sought in one of the stages of the Glacial period, when the region, considered as a whole, became isolated as far as human intercourse was concerned. Moreover, after this it probably took a long time for the reaction from the conditions induced by the ice-epoch to make much progress in breaking up the continuity of the loess-steppes and to widen the distance between habitable areas.

The reaction did not begin until the inflow of water became insufficient to maintain the inland sea at its maximum of expansion. After this came the change to segregation of communities, first into larger groups of loosely connected units, then the breaking up of these into smaller groups.

Within the wider limits of the region more or less intercourse could exist between the delta oases on some stretches along the piedmont belt, and often still more easily between those on opposite sides of relatively low mountain ranges. The essential condition was a sufficient frequency of springs or streams to permit travel on foot.

Under such conditions, continued through thousands of years, the related peoples becoming isolated, in oases and oasis groups, would differentiate, each evolving its own culture along lines influenced by inherited traditions, environment, and racial character.

The development would in general, on account of the isolation, be peaceful, and, while alone and uninterrupted, would lack the benefit of acquisition of the new factors that come with intercourse with unrelated peoples.

The growth of population on these restricted areas was necessarily accompanied by evolution in social organization. We find the people living in towns, and the long continuance of life under individual town government, practically without external relations, while developing great individuality, must have given the many peoples thus situated certain fundamental political characteristics common to all.

In the same way, in so far as the physical environment was similar, certain classes of customs, arts, and occupations must have evolved along similar lines.

In so far as the peoples of larger or minor groups of oases differentiated from the same stock or from the same language stock, their languages would retain traces of the original generalized speech.

All these are ethnographic data to be carefully searched for in sifting and analyzing the results of future investigations.

It is certain that during this physiographic condition of the region in question, before the domestication of the horse and camel, there could be no movement of population, nor of organized bodies of men, nor of individual across the broader-limiting deserts or waterless steppes.

There are, however, several data among our finds from this earliest Anau culture which show that a certain amount of intercourse existed with other parts of the oasis-world. Turquoise beads, which occur as burial gifts with the skeleton of a child, must have come from Persia,

where it is known both to the south of Anau and farther eastward on the plateau.

Again, the importation I have mentioned, of an already domesticated pig and goat, of which the wild forms exist in India and Persia, indicates a relation with at least eastern Persia or Afghanistan; and the possession of domesticated animals on other oases shows that the peoples of other parts of our oasis-world had passed the line that is held by many to mark the transition from barbarism to civilization.

It is hardly conceivable that, if the peoples of these distant oases had known the art of making, from stone, axes and points for arrows and spears, this knowledge would not have been imported with the turquoise, the pig, and the goat into Anau.

We have at present no means of knowing how the earliest culture of our settlements at Anau stands in relation to the generalized cultures of central Asia before the segregation into isolated communities, for there have been made no other systematic excavations anywhere to discover traces of the older civilizations.

The constituents of the earliest culture found at Anau presuppose an evolution during many thousand years. How slow it must have been is shown by the almost unvarying character of its pottery during the two millenniums of its existence at the north kurgan.

When we compare this culture with the two succeeding and intruding ones, we find both differences and points in common. Each has its own peculiar technique in pottery and scheme of design in painted decoration. All three have in common a rectangular construction of houses of air-dried bricks, with doors swinging on pivot-stones; the same spindle whorls, the same bottomless bake-oven pots, the same mealing stones; and through it all there persists the same custom of burying children under the house floor in a contracted position. The differences are due to independent culture evolution in separate oases of one or of several groups. But the points in common date from an earlier stage in the forming of groups and presuppose beyond doubt a long period of dwelling in houses and of knowledge of the potter's art and of spinning, and, if we may judge from the mealing stones, possibly some form, however primitive, of agriculture.

Of these the peculiar burial custom and the mealing stone probably date from a still earlier and regionally more generalized culture. Perhaps we may say the same of the bottomless bake-oven, for it exists in use today far and wide over Transcaspia and northern and eastern Persia. The earliest acquisitions are often the last to be lost.

We are thus carried back two stages in the progress of differentiation of oasis groupings beyond the founding of our earliest culture at Anau; and I think most modern ethnologists will agree that this means periods of thousands of years. But, however far back this may go, the time interval must have been many times greater that elapsed between the culture that built houses, had the art of spinning and a developed technique in pottery and design, and that remote and generalized stage of paleolithic humanity in which the stone arrow-point and axe were unknown.

All this points to a regionally widespread autochthonous culture evolution, which owed its generic character to its early regional isolation and its differentiations to the segregation into oasis groups imposed upon it by the regional progress of desiccation.

In this respect it is a unique ethnographic province and stands in strong contrast on the one hand with the West, where early man could move throughout Europe, Africa, and Asia Minor, and with northern Asia and the Americas.

Origin of Agriculture and of organized settled Society

With the gradual shrinking in dimensions of habitable areas and the disappearance of herds of wild animals, man, concentrating on the oases and forced to conquer new means of support, began to utilize the native plants, and from among these he learned to use the seeds of different grasses growing in the dry land and in the marshes at the mouths of larger streams on the desert.

With the increase of population and its necessities, he learned to plant the seeds, thus making, by conscious or unconscious selection, the first step in the evolution of the whole series of cereals.

For a long time the rainfall was doubtless sufficient to ripen grains, as it still is in some of the valleys of Ferghana, and in some years even at Samarkand.

Later, experience taught the need, and some simple method, of artificial watering, and in this acquisition lay the germ of agriculture and of the conquest of the arid regions of the globe.

In Asia it rendered possible the civilizations of Elam and Mesopotamia. All the really great prehistoric cultures were developed in arid regions—all of those of which we have knowledge, and perhaps others of which we have not yet found the remains, in Mongolia, Arabia, and the Sahara, while in America we have an instance in Peru. The

fertile loess on the semiarid borders of such regions and the equally generous soil of the delta oasis were the foundation on which the independent cultures of village communities were built up. Only later, when the knowledge thus obtained could be applied to the utilization of great rivers in turning wide deserts into gardens, was it possible to render populous great countries under the centralized power that constituted empire.

This stage was never fully reached in central Asia and northern Persia. The countless isolated oases, even under Chaldean, Persian, and Arab dominion, never advanced really much more than nominally beyond the feudal stage.

If the hypothesis outlined in the last pages be well founded in its essentials, it follows that where we find among the acquisitions of the earliest of the cultures at Anau resemblance to those of neolithic cultures in the West, such similarity can not be due to importation from the Western spheres. If they are not due to coincidence, these acquisitions must be considered as having originated in our oasis world, and to have been transported beyond its limits after the domestication of the horse, or of the horse and camel, rendered extended intercourse possible.

Among such acquisitions we must include a knowledge of copper and lead and I think also the art of spinning.

We have seen the birth of the great inner-continental region of the Eurasian continent. We have seen that from the very conditions of its birth it was predestined to a definite course of life history peculiar to its kind, and, treating it as an organic whole, we have seen this course toward ultimate desolation temporarily modified by the climate of the Glacial period.

What I wish particularly to emphasize is the conception that, in the intervention of the Glacial period and its reaction on the inner-continental conditions, we must see the initial—the motiving—factors in the evolution of the intellectual and social life of man.

Shut off from the periphery of Asia and from the other continents while still in a low stage of savagery, we see him gradually broken up into smaller groups, which are forced into isolation on, in the main, continually diminishing, habitable oases; and we see on these the growth of differentiated, but fundamentally related, cultures. Lastly, and most important of all to us, we see here man under the spur of Necessity, the relentless goddess of evolution, building in village communities, in

agriculture, and in the essential industries the foundation of civilizations, to the reaction of which upon cultures evolved in the oases of the Sahara, and on the Nile, and in Mesopotamia we owe the framework of modern Western civilization.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 17, PP. 671-785, PLS. 80-84 MARCH 30, 1907

PROCEEDINGS OF THE EIGHTEENTH ANNUAL MEETING, HELD AT OTTAWA, CANADA, DECEMBER 27, 28, AND 29, INCLUDING PROCEEDINGS OF THE SEVENTH ANNUAL MEETING OF THE CORDILLERAN SECTION, HELD AT BERKELEY, CALIFORNIA, DECEMBER 29 AND 30, 1905

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

Session of Wednesday, December 27

The Society was called to order by the President, Raphael Pumpelly, at 10.10 o'cock a m, at the Normal School, where all the sessions were held during the meeting except the evening session of this day.

By vote of the Society the address of welcome and response were postponed to the afternoon.

The report of the Council was called for, and was presented by the Secretary, in print, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Eighteenth Annual Meeting Assembled:

The stated Annual Meeting of the Council was held at Philadelphia conjointly with the meeting of the Society. It has been unnecessary to hold any special meeting, but some routine business has been done by correspondence.

The following reports of the officers give the details of administration for another prosperous year, the seventeenth, in the history of the Society.

SECRETARY'S REPORT

To the Council of the Geological Society of America:

Meetings.—The record of the Philadelphia Winter Meeting, 1904, will be found in the closing brochure of volume 16 of the Bulletin.

The adoption of the constitutional amendment relating to summer meetings gives the Council and Society liberty in the matter of summer meetings.

Membership.—Since the last publication of the list of Fellows, the names of two Fellows have been removed by death—George H. Eldridge and Albert A. Wright. The names of 15 new Fellows have been added to the list and one removed by resignation. This makes the present enrollment 271, or 12 more than at the last printing. Sixteen nominations are now before the Society and several candidates are awaiting action by the Council.

Distribution of Bulletin.—At this date 446 pages of volume 16 have been distributed and the remaining brochures are approaching completion. The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 33; sold to Fellows, 25. Brochures sent to supply deficiencies, 38; sold to the public, 34; sold to Fellows, 22. One copy of volume 15 has been donated and 3 copies bound for use of the officers and the Library. One complete set of the Bulletin volumes has been sold to a library and one set to a Fellow.

Bulletin Sales.—Receipts from the sale of the Bulletin during the past year appear in the following table:

Receipts from Sale of Bulletin, December 1, 1904, to December 1, 1905

	Complete volumes.			Brochures.			Grand total.
	Public.	Fellows.	Total.	Public.	Fellows.	Total.	
Volume 1..	$10 00	$9 00	$19 00	....	$0 65	$0 65	$19 65
Volume 2..	5 00	9 00	14 00	$0 50	......	50	14 50
Volume 3..	5 00	8 00	13 00	2 45	....	2 45	15 45
Volume 4..	5 00	7 00	12 00	80	....	80	12 80
Volume 5..	5 00	8 00	13 00	1 45	....	1 45	14 45
Volume 6..	5 00	12 00	17 00	1 00	....	1 00	18 00
Volume 7..	5 00	4 00	9 00	1 00	72	1 72	10 72
Volume 8..	5 00	4 00	9 00	25	40	65	9 65
Volume 9..	5 00	4 00	9 00	45	50	95	9 95
Volume 10..	5 00	4 00	9 00	....	20	20	9 20
Volume 11..	15 00	4 50	19 50	3 05	45	3 50	23 00
Volume 12..	19 95	4 00	23 95	....	1 20	1 20	25 15
Volume 13..	10 00	4 50	14 50	8 50	4 10	12 60	27 10
Volume 14..	50 00	4 50	54 50	2 70	2 75	5 45	59 95
Volume 15..	210 00	4 50	214 50	6 65	3 00	9 65	224 15
Volume 16..	195 00	....	195 00	65	....	65	195 65
Volume 17..	15 00	....	15 00	....	....	....	15 00
	$569 95	$91 00	$660 95	$29 45	$13 97	$43 42	$704 37
Index......	4 50	2 25	6 75	....	....	....	6 75
	$574 45	$93 25	$667 70	$29 45	$13 97	$43 42	$711 12

Receipts for the fiscal year	$711 12
Previous receipts, to December 1, 1904....................	8,154 97
Total receipts to date..............................	$8,866 09
Charged and uncollected..............................	29 10
Total Bulletin sales to date..........................	$8,895 19

The bills for volume 16 to regular subscribers have not been sent, and the above table includes for this volume only the payments in advance.

Exchanges.—The exchange list includes one more address than last year, three being added, two dropped, and one transfer made. The revised list will be found in the closing pages of volume 16.

Expenses.—The following table gives the cost of administration and of Bulletin distribution from the Secretary's office during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1905

Account of Administration

Postage and telegrams..	$29 76	
Expressage......	5 13	
Printing (including stationery)	110 74	
Total		$145 63

Account of Bulletin

Postage	$130 10	
Expressage and freight	66 87	
Wrapping material	50	
Addressograph links	56	
Binding three copies volume 15	3 00	
Bulletin advertising, Moore's catalogue	15 00	
Collection of checks	3 30	
Total		219 33
Total expenses for the year		$364 96

Respectfully submitted.

H. L. FAIRCHILD,
Secretary.

ROCHESTER, N. Y., *December 10, 1905.*

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1905.

Four (4) Fellows were liable to be dropped from the roll for non-payment of dues, in accordance with section 3, chapter 1; five (5) were delinquent for two years, while thirty-one (31) were still delinquent for this year on December 1, 1905. Since December 1 five (5) of them have paid, leaving only twenty-six (26) delinquent for 1905, and only two Fellows liable to be dropped at the present date (December 15).

Seven (7) Fellows—J. A. Bownocker, R. W. Brock, M. S. W. Jefferson, B. L. Miller, A. H. Purdue, S. Shedd, and Lewis G. Westgate—have enrolled for life by the payment of the one-hundred-dollar fee, thus increasing the total number of Life Commutations to seventy-five (75) to date.

The Permanent Publication Fund (only the interest of which can be used for current expenses of publication) has been increased during the year from $8,300 to $9,300 by the purchase of 10 more shares of stock in the Ontario Apartment House Company of Washington, D. C. This purchase was made upon the advice of the Treasurer and Doctor Emmons, two of the three members of the Finance Committee, since Doctor Walcott, the president of the Ontario Company, declined to advise the committee. The Treasurer has no doubt that the investment is a safe one, and that it will, like the other investments of the Society in this class of securities, continue to yield a 6 per cent annual dividend.

The item of annual interest from these investments ($448), together with the interest on monthly balances ($65.64), received on account of deposits in the Rochester Security Trust Company, thus continues to grow

Statement of Receipts and Expenditures

RECEIPTS.

Balance in treasury December 1, 1904			$1,973 68
Fellowship fees 1902 (2)	$20 00		
" " 1903 (9)	90 00		
" " 1904 (29)	290 00		
" " 1905 (160)	1,600 00		
		$2,000 00	
Initiation fees (15)		150 00	
Life commutations (7)		700 00	
Interest on investments:			
Iowa Apartment House Co. stock	$120 00		
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00		
Ontario Apartment House Co. stock	60 00		
Texas and Pacific R. R. bonds	100 00		
U. S. Steel Corporation bonds	150 00		
Interest on deposits with Security Trust Company of Rochester	65 64		
		513 64	
Sales of publications		711 12	
			4,074 76
Total receipts (carried forward)			$6,048 44

Total receipts brought forward			$6,048 44

EXPENDITURES.

Secretary's office:			
Administration	$145 63		
Bulletin	219 33		
Allowance (traveling and clerical expenses)	500 00		
		$864 96	
Treasurer's office:			
Postage	$10 00		
Expressage	1 35		
		11 35	
Librarian's office		8 26	
Photographic account		14 20	
Publication of Bulletin:			
Printing	$1,564 90		
Engraving	725 51		
Editor's allowance, personal and office expenses	250 00		
		2,540 41	
Investments, Ontario Apartment House Co. stock		1,000 00	
Total expenditures			4,439 18
Balance in treasury December 1, 1905			$1,609 26

and practically offset the loss in fees from deaths and resignations, so that the financial affairs of the Society are in a satisfactory condition, as may be seen from the receipts and disbursements for the past year exhibited by the tabular statement on the preceding page.

The securities now owned by the Society (all of which are deposited in the fire and burglar proof vaults of the Bank of the Monongahela Valley at Morgantown, West Virginia) are as follows:

On Account of Publication Fund

March 17 and 25, 1898, two Texas and Pacific Railroad first mortgage 5 per cent bonds, cost $1,976.25	$2,000
February 6, 1901, 10 shares of the capital stock of the Iowa Apartment House Company, Washington, D. C., cost $1,000	1,000
April 1, 1903, 20 shares of the capital stock of the Ontario Apartment House Company, Washington, D. C., cost $2,000	2,000
May 5 and September 27, 1895, 3 first mortgage 6 per cent bonds of the Kingwood, Tunnelton and Fairchance railroad, cost $304	300
April 11, 1904, 3 second mortgage 5 per cent bonds, United States Steel Corporation, cost $2,366.25	3,000
May 12, 1905, 10 shares of the capital stock of the Ontario Apartment House Company, Washington, D. C., cost $1,000	1,000
Total cost, $8,646.50; total par value	$9,300

The Texas and Pacific and United States Steel bonds are quoted on the New York Exchange at 123 and 96½, respectively, at the date of this report.

Respectfully submitted.

I. C. White,
Treasurer.

Morgantown, W. Va.,
December 15, 1905.

Editor's Report

To the Council of the Geological Society of America:

The Editor regrets to have to report again inability to close the annual volume before the Winter Meeting, owing to the tardiness of members in handing in their papers. The last galleys, and even the illustrations of one paper, were not in the Editor's hands before the middle of December. At this writing all papers are in pages, the last page being 670. The Proceedings Brochure, now in galleys, will add something over 100 pages. From this it will be seen that volume 17 will probably be the largest ever issued by the Society. It is copiously illustrated with over 80 half-tone plates and many text figures.

The Bulletin is certainly appreciated by the members as a medium of publication, the demand for space in its pages steadily growing as time goes on.

The foregoing was the Editor's report to the Council on December 20, 1906. It has seemed to him wise to append the facts concerning volume

17 as well as volume 16, and thus bring the statistical information down to date, rather than to wait for another year to pass.

In text volume 17 is the largest ever published by the Society. It will be seen from the data given below that its cost is proportionately large. It contains 785 pages, 84 plates, and 96 text figures.

	Average. Vols. 1–10.	Vol. 11.	Vol. 12.	Vol. 13.	Vol. 14.	Vol. 15.	Vol. 16.	Vol. 17.
	pp. 544. pls. 26.	pp. 651. pls. 58.	pp. 538. pls. 45.	pp. 583. pls. 58.	pp. 609. pls. 65.	pp. 636. pls. 59.	pp. 636 pls. 94	pp. 785 pls. 84
Letter-press.........	$1,465 14	$1,815 56	$1,445 73	$1,647 12	$1,657 50	$1,661 21	$1,817 03	$2,087.98
Illustrations........	200 40	373 68	414 80	477 27	431 21	457 76	706 97	608.68
	$1,665 54	$2,189 24	$1,860 53	$2,124 39	$2,088 71	$2,118 97	$2,524 00	$2,696.66
Average per page	$3 23	$3 36	$3 45	$3 64	$3 43	$3 33	$3 96	$3.37

Attention is called to the fact that in presenting the analyses of the contents of volumes a change has been made in the divisions of the subject-matter. It is believed that the new classification will be found more satisfactory than the one previously used. The analyses now include volumes 1 to 6, thus making the entire series complete.

Classification

Volume.	Areal geology.	Physical geography.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1......	116	137	92	18	83	44	47	.....	60	4	4	593 + xii
2	56	110	60	111	52	168	47	9	55	1	7	662 + xiv
3.. ..	56	41	44	41	32	158	104	.....	61	15	1	541 + xii
4	25	134	38	74	52	52	14	.....	47	32	2	458 + xii
5	138	135	70	54	28	51	107	.....	71	14	9	665 + xii
6	50	111	75	39	71	99	1	.....	63	25	4	538 + x
7	38	77	105	53	40	21	123	4	66	28	13	558 + x
8......	34	50	98	5	43	67	58	14	79	8	....	446 + x
9......	2	102	138	.....	44	28	64	16	64	12	....	460 + x
10......	35	33	96	37	59	62	68	28	84	27	17	534 + xii
11......	65	110	21	10	54	31	188	7	71	60	46	651 + xii
12......	199	39	55	53	24	98	5	5	70	2	....	538 + xii
13......	125	17	13	24	28	116	42	4	165	32	29	583 + xii
14	48	47	48	59	183	118	22	1	80	14	1	609 + xii
15......	26	124	3	94	36	267	.....	.....	77	17	3	636 + x
16	64	111	78	30	102	141	19	.....	67	22	15	636 + xii
17	49	161	41	84	47	294	27	.....	71	9	2	785 + xiv

Respectfully submitted.

JOSEPH STANLEY-BROWN,
Editor.

NEW YORK, *March 15, 1907.*

Librarian's Report

To the Council of the Geological Society of America:

The accessions to the library received during the past twelvemonth have been duly catalogued and acknowledged and the list of accessions up to July 1, 1905, prepared and forwarded to the Secretary for incorporation in volume 16 of the Bulletin.

The library now contains some 2,800 numbers, which is an average of about 200 numbers annually since library material first commenced to accumulate. At present the increase is slightly in excess of that figure, owing mainly to an increase in the number of contributing exchanges. The amount of material donated by Fellows shows a steady annual decrease. If it is desirable that the library should contain a full representation of the writings of its members, then it should be stated that at the present time it falls far short of so doing, and in increasing annual amount.

It has never been feasible for the Society to exchange publications with state surveys, but it was thought that the officials of such surveys who are Fellows of the Society would see to it that sets of their publications reach the library shelves. They do so, but in diminishing number. The Librarian does not understand it to be part of his duties to solicit gifts to the library; but he wishes to call attention to the fact that only a small percentage of the annual output of state survey reports reach the library.

The expenses of this office for the past year are as follows:

To postage	$1 76
To express charges	50
To clerk hire	6 00
	$8 26

Respectfully submitted.

H. P. Cushing,
Librarian.

Cleveland, Ohio, *December 1, 1905.*

On motion of the Secretary, it was voted to defer the consideration of the Council report until the following day.

As the Auditing Committee to examine the accounts of the Treasurer, the Society elected W. H. Sherzer and F. D. Adams.

ELECTION OF OFFICERS

The result of the balloting for officers for 1906, as canvassed by the Council, was announced by the President, and officers were declared elected as follows:

President:

I. C. Russell, Ann Arbor, Mich.

First Vice-President:

W. M. Davis, Cambridge, Mass.

Second Vice-President:

E. A. Smith, University, Ala.

Secretary:

H. L. Fairchild, Rochester, N. Y.

Treasurer:

I. C. White, Morgantown, W. Va.

Editor:

J. Stanley-Brown, Cold Spring Harbor, Long Island.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councillors:

A. C. Lane, Lansing, Mich.
David White, Washington, D. C.

ELECTION OF FELLOWS

The Secretary announced that the candidates for fellowship had received a nearly unanimous vote of the transmitted ballots, and that Fellows were elected as follows:

Sydney Hobart Ball, A. B., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

John Mason Boutwell, A. B., S. B., M. S., Washington, D. C. Geologist, U. S. Geological Survey.

Amos Peaslee Brown, B. S., E. M., Ph. D., Philadelphia, Pa. Professor of Mineralogy and Geology, University of Pennsylvania.

Frederick G. Clapp, S. B., Washington, D. C. Geologic Aid, U. S. Geological Survey.

Herdman Fitzgerald Cleland, A. B., Ph. D., Williamstown, Mass. Professor of Geology, Williams College.

Reginald Aldworth Daly, A. B., A. M., Ph. D., Ottawa, Canada. Geologist for Canada on the International Boundary Commission.

Edwin Clarence Eckel, B. S., C. E., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

Edward Martin Kindle, A. B., M. S., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

JOHN DUER IRVING, A. B., A. M., Ph. D., South Bethlehem, Pa. Assistant Professor of Geology, Lehigh University; Assistant Geologist, U. S. Geological Survey.

ALBERT PETER LOW, B. S., Ottawa, Canada. Geologist, Geological Survey of Canada.

RUDOLPH RUEDEMANN, Ph. D., State Hall, Albany, N. Y. Assistant State Paleontologist.

ELIAS HOWARD SELLARDS, B. A., M. S., Ph. D., Lake City, Florida. Professor of Geology, etc., in University of Florida.

FRANK ALONZO WILDER, A. B., Ph. D., Iowa City, Iowa. Professor of Economic Geology and Mineralogy, University of Iowa, and State Geologist.

IRA ABRAHAM WILLIAMS, B. Sc., M. Sc., A. M., Ames, Iowa. Teacher, Iowa State College.

JOSEPH EDMUND WOODMAN, S. B., A. M., S. D., Halifax, N. S. Assistant Professor of Geology and Mineralogy, Dalhousie University.

GEORGE ALBERT YOUNG, B. A. Sc., M. Sc., Ph. D., Ottawa, Canada. Geologist, Geological Survey of Canada.

AMENDMENT TO CONSTITUTION

The Secretary announced that the transmitted ballots on the proposed changes in Article VI of the Constitution, as canvassed by the Council, showed an affirmative vote in excess of three-fourths of the total membership of the Society, and were therefore adopted as follows:

Change Article VI, Meetings, section I, by dropping the matter in italics in the following quotation:

I. "The Society shall hold at least *two* stated meetings a year—*a summer meeting at the same locality and during the same week as the annual meeting of the American Association for the Advancement of Science—and a winter meeting.* The date and place of the winter meeting shall be fixed by the Council, and announced *by circular* each year within *a* month after the adjournment of the *summer* meeting." . . .

And by making insertions so that the section shall read as follows:

I. The Society shall hold at least one stated meeting a year, in the winter season. The date and place of the winter meeting shall be fixed by the Council, and announced each year within three months after the adjournment of the preceding winter meeting.

The President called for the necrology, and memoirs of deceased Fellows were presented as follows:

*MEMOIR OF GEORGE H. ELDRIDGE**

BY WHITMAN CROSS

In the death of George Homans Eldridge, which occurred on June 29, 1905, at Washington, D. C., American geology lost one of its most enthu-

* This memoir was not read, on account of the author's absence, but is here inserted in its proper place.

siastic and devoted workers. Those who were fortunate enough to know him mourn his untimely end, both because of the promise, which can not now be fulfilled, of further important contributions to knowledge and of the loss of a friend of singularly attractive and lovable personality. Eldridge possessed many traits worthy of all admiration, and it is befitting to place in the records of this Society a tribute to his memory, both as a geologist and as a man.

The subject of this sketch was born in Yarmouth, Massachusetts, December 25, 1854, the son of Ellery and Sarah (Matthews) Eldridge. His early education was first in the public schools of Yarmouth and later in the Boston Latin School, whence he went to Harvard University, graduating in the class of 1876.

There is nothing in the statements I have seen concerning Eldridge's boyhood to indicate a special predilection for scientific studies; but it is of record that he was greatly interested in the military training given to the Latin School pupils, and he rose from the ranks of the cadets to become lieutenant colonel at graduation. This love of the military work and discipline led him to organize a company of Harvard students, of which he became captain. There can be no question in the minds of all who have known Eldridge's energy and persistence that the boys under his command got a good insight into the meaning of military discipline, and that they received a training that was good for them.

Not long after graduation from Harvard the estate left by Eldridge's father became much involved, through no fault of his, and he resorted to teaching as a means of support. He was first located at Mount Vernon, New Hampshire (1876-1877), and for two years (1877-1879) at Nahant, Massachusetts, as principal of the High school. While at Nahant he passed examinations qualifying him to teach in the Boston Latin and other high grade schools of the Boston system, but at this point circumstances transpired which turned him to his life work in geology.

While it does not appear that Eldridge had specialized in geology in his university studies, he had availed himself of the opportunity afforded by the summer school of geology conducted by Professor Shaler at Cumberland Gap, Kentucky, in connection with the State Geological Survey. Eldridge was a member of that school, both in 1875 and 1876. A general fondness for natural science may be inferred from the courses of public lectures given at Nahant, and that the trend of his interest had been turned toward geology is shown by the fact that, while teaching at Nahant, Eldridge was taking private instruction in geology from Professor Shaler.

The opportunity to take up the profession of geologist came through the demand for young men to study the mining industry of the country in connection with the Tenth Census. That undertaking was placed in charge of the newly formed U. S. Geological Survey, and the study of the iron and coal industries was assigned to Professor Raphael Pumpelly. He applied to Professor Shaler to recommend assistants. Eldridge was one of those chosen, and in the summer of 1879 he entered upon that work. He was assigned to study the deposits of the baser metals in the southern Appalachian region and also the coal fields of northern Montana. The results of this work were published in the Census report, as cited in the appended bibliography (1, 2).

About the time that the Census work was completed the Northern Transcontinental Survey was organized to examine the mineral resources along the route of the Northern Pacific railroad. This survey was placed in charge of Professor Pumpelly, and Eldridge was naturally one of the first to be employed. He was engaged in this work for about four years, studying especially the coal fields of Dakota and Montana. Owing to the abandonment of the Survey in 1884, much of Eldridge's scientific work of this period never came to publication. The discussion of Montana coal fields in the reports of the Tenth Census embodied much of this information.

From the summer of 1884 until his death Eldridge was connected with the U. S. Geological Survey. For the first six years of this period his field of work was in Colorado, as assistant to S. F. Emmons. It was as his colleague during these happy years that the writer of this sketch came to know Eldridge and to love him for his many noble and attractive traits of character.

The principal results of Eldridge's Colorado work, under Mr Emmons, appear in the Anthracite-Crested Butte folio (10) ; in the monograph on the Geology of the Denver basin (15), and in a sketch of the complex stratigraphy and structure of the foothill belt about Golden (6).

The study of the Cretaceous in Colorado and Montana led Eldridge to propose the union of the Fort Pierre and Fox Hills as the Montana formation or group (5).

In 1890 Eldridge investigated the first productive oil field of the western Cretaceous at Florence, in Colorado, and wrote an account which has served to direct the work of development in that interesting field (7).

In 1891 Eldridge was given independent work, and his first assignment was to the investigation of the phosphate deposits of Florida. That this study was never completed was not the fault of the geologist; the exigencies of Survey work led to his repeated assignment to investigations

deemed of more urgent importance. With each postponement of this study the amount of development in the phosphate area increased greatly, so that the field work was never completed. In fact, the last visit to the Florida phosphate diggings was made by Eldridge only a few months before his death. A preliminary report was published in 1893, giving a summary of his observations to that time (8).

The great energy and endurance possessed by Eldridge, as well as his ability to grasp the broad features of geology in a new country, led to several assignments in reconnaissance work. In the seasons of 1893 and 1894 he was engaged in surveys of this character in northwestern Wyoming and northeastern Idaho. Two valuable reports were the results of this work (11 and 12).

Again, in 1898, with the beginning of Alaskan exploration by the Geological Survey, Eldridge was called on for genuine reconnaissance work. He was placed in charge of the work of several parties, and himself conducted one of them through a wild and quite unknown territory north of Cooks inlet, within which is Mount McKinley, the highest point in North America. It is believed by his friends that the exposure and strenuous exertions of this season's work seriously impaired Eldridge's vitality. It was too much for a man of 44 years to undergo without lasting injury. His reports appear in the Survey publications cited in the bibliographic list (16 and 17).

In the summer of 1899 Eldridge was assigned to the comprehensive study of the asphalt and bituminous rock deposits of the country. His investigations were carried on in many states and concerned deposits of various characters. The field work occupied more than a year's time and the report is really a monographic discussion of a class of deposits which had previously received scarcely any attention. This is probably the most important single contribution to science made by Eldridge (18).

Soon after the completion of the asphalt report the investigation of important oil fields in southern California, in a region of much structural complexity, became a matter of great interest, and it was entrusted to Eldridge. After a vast amount of labor, which was rendered doubly difficult by the rapid development of the oil fields, he had nearly completed his report on some important sections of the district when attacked by his last illness. It is to be hoped that some part of the material may appear under the name of the man whose career has unhappily been cut short before he could complete his work. A preliminary statement concerning the field was issued in 1903 (21).

The last fruit of Eldridge's wide experience was dictated from his bed of suffering not long before the end. It was a summary of his views

regarding the origin of vein asphalt, one of the singular phenomena investigated some few years ago (22).

The illness which terminated this career, with its promise of still higher achievements, seems to have begun in the autumn of 1904. After several months of uncertainty as to its nature, it became evident that an operation was necessary to remove an internal growth of problematic character. The relief afforded by the operation was not lasting, and with the renewal of the sarcomatous growth the end was inevitable. Almost to the last the patient exhibited his customary cheery courage and had faith in his ultimate recovery.

The scientific work accomplished by Eldridge was of the highest order in many respects. He was not much given to theorizing, choosing to stick close to the firm ground of established fact. His investigations were characterized by thoroughness and by infinite patience in the accumulation of facts bearing on his problem. His aim seemed to be to exhaust the subject so far as time and conditions would permit. To ascertain and make known the exact truth was his ambition. As a result of fidelity to this high ideal, he gathered a vast store of information in each of his more important investigations, and in that it was not granted him to utilize a great part of this knowledge to the full, in mature and well considered discussion, must be a source of keen and lasting regret.

While an adequate tribute to the estimable personality possessed by Eldridge, such as his friends may desire to see put on record, is perhaps not in place in this publication, this sketch would be far from satisfactory without some appreciative notice of the traits which endeared our friend to all who were privileged to know him. His was a character such as all admire, and to know the possessor was to love him; blessed with a fine physique and great strength, Eldridge seemed always in high spirits and overflowing with good cheer. The power to brighten with his presence was felt by all with whom he came in daily contact, and among all ranks of the great organization to which he belonged his death caused the feeling of personal loss, even to many who could not claim direct acquaintance. A fund of anecdote in illustration of this influence for good might be cited.

For many years physical strength and great power of endurance stood Eldridge in good stead in trying circumstances. Professor Pumpelly tells in a personal letter how, during his work for the Transcontinental Survey in Montana, Eldridge rose from his bed after a severe attack of typhoid fever, and, in spite of his physician's orders, proceeded with the task assigned him to find and explore certain coal beds in an undeveloped district. It was early winter and severe snow-storms had driven out rail-

road surveyors and others, who told Eldridge that the locality he sought to reach was inaccessible; but he continued his journey, found the coal buried under heavy snow-drifts, opened and sampled it, and returned in safety. In the writer's own experience with Eldridge in the field, there have been many illustrations of his phenomenal endurance and grim determination—a combination of qualities making it a hopeless task for one of average powers to compete with him in many undertakings. When engaged in the preparation of reports Eldridge has been known to work without sleep for nearly 48 hours and seem to suffer no ill effects.

A good comrade and loyal friend, Eldridge was also a beautiful example of the devoted son. His aged and infirm mother found with him during her declining years a home of many comforts, such as could be supplied only by cheerful sacrifices. Soon after the death of his mother Eldridge was married to Miss Jessie Newlands, of San Francisco, who survives him.

Eldridge was a man of much modesty, never putting himself forward except as a duty. His ideals were those of the Christian gentleman, and hence his influence for good was always felt by those within his sphere of life. Many will join in the tribute of his old instructor and friend, the late Professor Shaler, who wrote of him:

> "He will remain with me as the type of the strong, well-balanced man; brave, steadfast, patient in his duties, ever friendly with his neighbor, helpful with his friends—I feel that my contacts with him served to ennoble my life."

List of Publications

(1) Montana coal-fields. Tenth Census of the United States, 1879-1880, vol. xv, 1886, pp. 739-757.

(2) The industries of the base metals (lead, zinc, and copper) in the census year. Tenth Census of the United States, 1879-1880, vol. xv, 1886, pp. 809-830.

(3) On some stratigraphic and structural relations of the country about Denver, Colorado. Mining industry (Denver, Colorado), vol. iii, no. 3, 1888, pp. 24-25; no. 4, pp. 33-35; no. 5, pp. 44-45.

(4) On some stratigraphical and structural features of the country about Denver, Colorado. Proceedings of the Colorado Scientific Society, vol. iii, 1888, pp. 86–118.

(5) Some suggestions upon the method of grouping the formations of the Middle Cretaceous and the employment of an additional term in its nomenclature. American Journal of Science, vol. xxxviii, October, 1889, pp. 313-321.

(6) On certain peculiar structural features in the foothill region of the Rocky mountains near Denver, Colorado. Bulletin of the Philosophical Society of Washington, vol. xi, 1892, pp. 247-274.

(7) The Florence oil field, Colorado. American Institute of Mining Engineers Transactions, vol. xx, 1892, pp. 442-462.

(8) A preliminary sketch of the phosphates of Florida. American Institute of Mining Engineers Transactions, vol. xxi, 1893, pp. 196-231.

(9) Artesian wells of eastern Dakota. Compte Rendu, International Congress of Geologists, 5th session, 1893, p. 318.

(10) Anthracite-Crested Butte folio, Colorado (in conjunction with S. F. Emmons and C. Whitman Cross). Geologic Atlas of the United States, folio 9, U. S. Geological Survey, 1894.

(11) A geological reconnaissance in northwest Wyoming. Bulletin no. 119, U. S. Geological Survey, 1894, pp. 72.

(12) A geological reconnaissance across Idaho. 16th Annual Report, U. S. Geological Survey, pt. 2, 1895, pp. 211-276.

(13) Occurrence of uintaite in Utah. Science, new series, vol. iii, 1896, pp. 830-832.

(14) The uintaite (gilsonite) deposits of Utah. 17th Annual Report, U. S. Geological Survey, pt. 1, 1896, pp. 909-949.

(15) Geology of the Denver basin in Colorado (in conjunction with S. F. Emmons and C. Whitman Cross). Monograph no. 27, U. S. Geological Survey, 1896, pp. 556.

(16) Report of the Sushitna expedition (in conjunction with Robert Muldrow); the extreme southeastern coast; the coast from Lynn canal to Prince William sound; the Sushitna drainage area; maps and descriptions of routes of exploration in Alaska in 1898, with general information concerning the territory. Special Publication of the U. S. Geological Survey, 1899, pp. 15-27, 101-102, 103-104, 111-112.

(17) A reconnaissance in the Sushitna basin and adjacent territory, Alaska, in 1898. 20th Annual Report, U. S. Geological Survey, pt. 7, 1900, pp. 7-29.

(18) The asphalt and bituminous rock deposits of the United States. 22d Annual Report, U. S. Geological Survey, pt. 1, 1901, pp. 209-464.

(19) The petroleum industry of California. Engineering and Mining Journal, vol. 73, 1902, p. 41.

(20) Origin and distribution of asphalt and bituminous rock deposits in the United States. Bulletin no. 213, U. S. Geological Survey, 1903, pp. 296-305.

(21) The petroleum fields of California. Bulletin no. 213, U. S. Geological Survey, 1903, pp. 306-321.

(22) The formation of asphalt veins. Economic Geology, vol. i, no. 5, March-April, 1906.

MEMOIR OF ALBERT ALLEN WRIGHT

BY FRANK A. WILDER

Albert Allen Wright, a Fellow of this Society since 1893, died at Oberlin, Ohio, on April 2, 1905, after an illness of a single day. While his health had been somewhat impaired for some time before his death, he was not greatly hindered in his activities as a teacher and investigator till the day before his death.

Professor Wright was born at Oberlin, Ohio, in 1846, and was intimately identified with the interests of that community, both town and college, during his entire lifetime. He was graduated at Oberlin in 1865, and, as a number of scientists have done whose names appear on the roll of Fellows of this Society, he filled out his studies by a course in theology. A degree in theology was given him by Oberlin in 1870, after three years of study at Union and Oberlin seminaries. After two years of teaching, he entered Columbia School of Mines and was graduated from this institution in 1875. In later years his education was broadened by extended travels in regions of geologic interest in Europe and America.

In 1874 Professor Wright was married to Mary Bedortha, and some time after her death, to Mary P. B. Hill, in 1891. A daughter from his first marriage survives him, and a son from his second.

Before he had completed his course at Columbia he was called to the chair of geology and natural history in Oberlin College, a position which he held for 30 years. He directed the development of the work in zoology and botany till separate departments were formed for these sciences, and retained for himself the work in geology, which best fitted his taste in teaching and research. All of the departments of natural science in Oberlin, however, show his capacity as an organizer and owe to him in a large measure their present development.

The greater part of his energies were spent in the class-room and laboratory, where he served as a faithful guide to hundreds of students, many of whom, on account of his leadership, devoted themselves in later life to scientific pursuits. His capacity as a man of affairs was recognized by the community in which he lived, and it looked to him to solve its problems in municipal engineering, or at least to suggest the lines along which solutions might be hoped for. The systems of city water supply and sewerage in Oberlin are wholly his work. After a thorough study of local topography and drainage, he directed the installation of what is regarded in Ohio as the model equipment of the state. He secured for the town perfect sanitation and an abundant and pure supply of water at an expense far below that estimated by capable engineers.

To the persistence and patience of Professor Wright, the cooperative topographic survey now being made in Ohio is due. At first, he labored toward this end almost without assistance. When President of the Ohio Academy of Sciences he brought the matter forward in an address. Few came to his aid, but he persisted in circulating his address, in writing letters, and in speaking on the subject on all suitable occasions. His system of instruction gradually developed a demand for topographic work. In spite of his untiring efforts, he saw his measure defeated at

Columbus. He began again, however, as though he had received no rebuff, and in the end his perseverance was fully rewarded. His efforts were made, not as an officer of the State Geological Survey, but as a private citizen, eager to advance a cause which he regarded as good. His papers urging topographic work have proved helpful in presenting the matter of topographic mapping to the legislatures of a number of states.

Professor A. A. Wright possessed in a very large measure the scientific spirit. He was careful and deliberate. He was slow in forming judgments, yet persistent in accumulating material on which a rational judgment could be based. With such a temperament, it is not surprising that his contributions to the science to which he was devoted are of the highest order in quality. They might have been notable in quantity had he not sacrificed any desire for personal distinction to the welfare of the college to which he gave such a full measure of his time. His more important geological work has to do largely with his native state. In 1874 he began field work on the lake ridges of Lorain county. His published results were valuable, and left nothing to be added concerning the surface features of this portion of Ohio. In 1893 he reported on the ventral armor of Dinichthys for the Ohio Survey, and, aided by excellent specimens secured in Lorain county, he was able to supplement and to modify in a number of important particulars the descriptions of Newberry. His reports of certain coal beds in Ohio and on drift and glaciation in New Jersey are represented by a number of titles in geologic magazines, in the bulletins of this Society, and in the Proceedings of the Ohio Academy of Sciences. At the time of his death he was at work with thin-sections of bryozoans, and hoped to be able to add something of value to the limited literature on these difficult organisms.

Professor Hall, a colleague of Professor Wright for years, sums up his life most justly:

"Outside of Oberlin, he might have made a much larger reputation as an earnest investigator and sound reasoner upon scientific topics, and as a master of an unusually clear and chaste literary style, if he had been willing to take a larger place in the scientific assemblies of his time. He might have written books which would have proved helpful to the thought of his time, especially as bearing on the interpretation of science. As a teacher, he might have attracted larger classes and might have made a superficial impression on a larger number of pupils, if he had cared to make more parade of his learning. But he chose to do his work quietly, with no desire to do anything that should dazzle, but with a fixed purpose to do everything in the most thorough and faultless manner. The true scientific spirit mastered him as it has mastered few minds in his generation, and, slender as might seem his technical training, it made it impossible for him to approach any topic without the most painstaking and careful investigation, seemingly without the least prejudice as to the outcome of his research."

It is not strange, therefore, that his life proves a constant light to the considerable number of his students who have chosen for their life work some form of scientific pursuit.

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Classification of the animal kingdom. Translation from Hertwig, Richard. Lehrbuch der Zoologie.

Early embryonic stages of Amphioxus, pp. 4.

General Zoology, pp. 4.

Optical properties of rock-making minerals, pp. 8.

Rocks, pp. 17.

Students' collections of fossils, pp. 4.

The dissection of molgula, pp. 7.

Following the reading of the memoirs the Secretary presented letters from several Fellows who were unable to attend the meeting, but had sent their greeting; and Mr H. M. Ami, chairman of the local committee of arrangements, made announcements relating to the evening sessions and the social functions.

The President declared the scientific program in order. The first paper presented was the following:

CHEMICAL EVOLUTION OF THE OCEAN

BY ALFRED C. LANE

[*Abstract*]

If there is any value in the numerous attempts, by Joly and others, to estimate the age of the earth from the accumulation of some salt in the ocean, there must have been a progressive change in the chemical character of the ocean, which might possibly be detected in comparing the waters buried in undisturbed sediments of various ages.

The paper applies this test to the deepest waters known from various geological horizons in the Lower Michigan and Lake Superior basins. Both basins are as permanent and free from recent igneous disturbance or faulting or inverted siphon circulation, etcetera, as are readily found.

The proportions of many ions are likely to be changed by reactions after burial. The ratio of chlorine to sodium seems to be among those least changeable, thus: This ratio is in sea water 25,440 (trillion tons) to 14,151 (trillion tons)=1.77, while in the river waters delivered each year it is 84 (million tons) to 157 (million tons). Whence, *unless there is some large source of chlorine apart from sodium or precipitation of sodium apart from chlorine*, n years ago the ratio must have been about $R = (25{,}440 - .000{,}084n)/(14{,}151 - .000{,}157n)$. For instance, we have from the Upper Subcarboniferous of Big Rapids $R = 2.14$, $n = 20$ million years; similarly from the Berea grit at Bay City 45 million years; from the meso-Devonian at Alma 49 million years; from the Silurian at Manistee 65 million years; from the Upper Keweenawan at Freda 72 million years; from the Tamarack mine, Lower Keweenawan, 89 million years. These figures suggest some agreement with the hypothesis, but a more careful examination reveals serious difficulties, as is more fully presented in the paper.

The paper was discussed by J. F. Kemp, A. P. Coleman, and the author.

The second paper was

DIKE OF MICA-PERIDOTITE FROM FAYETTE COUNTY, SOUTHWESTERN PENNSYLVANIA

BY J. F. KEMP

[*Abstract*]

The dike occurs on the surface and in the coal mines on Middle run, a tributary of the Monongahela, in the Masontown quadrangle. It cuts the Carboniferous to and above the Waynesburg coal seam and reveals eruptive rocks in a hitherto unsuspected region. The petrographic details were briefly given and comparisons were made with other similar occurrences. The full paper will be published elsewhere.

The author replied to questions by A. C. Lane.

The last paper of the morning session was

SAPPHIRE; ITS OCCURRENCE AND ORIGIN

BY W. H. COLLINS*

Remarks were made by T. L. Walker. The Society adjourned for the noon recess.

At 2.30 o'clock p m the Society reconvened and an address of welcome was given by Dr Robert Bell, Acting Deputy Head and Director of the Geological Survey of Canada. A brief response was made by President Pumpelly.

Announcement was made that from 4.30 to 7.00 o'clock p m Dr and Mrs Robert Bell would receive the Fellows of the Society at their home.

The scientific program was resumed, and the following paper, in the absence of the author, was presented briefly by J. F. Kemp:

OCCURRENCE OF THE DIAMOND IN NORTH AMERICA

BY GEORGE F. KUNZ

[*Abstract*]

The great advance in the prices of diamonds within a few years past, together with the fact that the demand for diamonds has become so large in this country, has stimulated interest in the question of the possible discovery of diamond mines in the United States. This whole subject has been treated of in some detail in a bulletin by the writer to the U. S. Geological Survey, now about to be issued. Diamonds have been found at various points in our territory, though never of large size or in any abundance; but the facts are of much interest as they are here gathered and presented.

There are four regions where diamonds have been met with in the United States. These are: (1) the Pacific coast, chiefly along the western base of the Sierra Nevada, in the central counties of California, associated with gold in the cement gravels; (2) along the line of the moraine of the ancient ice-sheet of the Glacial epoch of geology, in Wisconsin, Michigan, Indiana, and Ohio; these have been transported from an undiscovered source somewhere in Canada; (3) a few only in central Kentucky and Tennessee; (4) the Atlantic states from Virginia to Alabama, chiefly along the eastern base of the Appalachians, in what is known as the Piedmont region. The actual place of the origin of the diamonds is in all these cases unknown. Those of the Pacific coast and the Atlantic states have been derived by erosion from the adjacent mountain ranges, but the original sources have never been discovered. Those of the northern drift have come from beyond our borders, in Dominion territory, and their exact source is entirely a matter of speculation. The few occur-

* Introduced by T. L. Walker.

rences in Tennessee and Kentucky are not as yet definitely traceable, even in theory. All have been found in loose and superficial deposits and all accidentally; most of those in the Atlantic and Pacific regions have been found in washing for gold.

Historically, the first diamond recognized in the United States appears to have been found in 1830, in central Indiana; it came finally into the hands of the well known artist, the late James W. Beard, who wore it for over 50 years. No others appear to have been found in this region until within the past quarter century, when several were obtained in the glacial drift, and their peculiar transported character began to be understood.

The finding of diamonds in the gold washings of northern Georgia goes back by local tradition to the "forties," but definite records of such discoveries do not begin until some years later, when a few were found in North Carolina. The largest stone ever obtained in the United States, the celebrated Dewey diamond, of 23¾ carats, was found in 1855, by a laborer while digging in a bank, at Manchester, Virginia, nearly opposite Richmond. Two have been met with lately in Alabama, and there may be in all twenty or twenty-five diamonds known from the southern Atlantic states.

The first diamond in California was recognized in 1849, soon after the discovery of gold, but no particular accounts are on record until 1853. Altogether, some 200 small diamonds have been reported from this State, most of them from the four counties of Amador, Butte, El Dorado, and Nevada; the last named has yielded only a few, but one of these is the largest known from California, a stone of 7¼ carats. All have been discovered in connection with gold-mining, and most of them in the hard "cement" gravel, overlain and compacted by beds of lava or volcanic tufa. Of late years but few have been obtained, though many fragments appear in the sluices; but the general use of hydraulic mining and stamp mills causes any diamonds that may exist to be either swept away and buried in the debris or else crushed into bits by the stamps. This seems very regrettable; but the amount of diamonds that might be saved by the use of other methods would not probably compensate at all for the cost of installing different processes from those now employed. Notwithstanding this, it is stated that two companies have been formed for the purpose of searching for diamonds in Amador and Butte counties.

The diamonds of the northwestern drift began to attract attention about fifteen years ago, when several in succession were found in Wisconsin; some of these had been picked up years before and kept as curiosities, without knowledge of what they were. Professor W. H. Hobbs, of the State University at Madison, made a very careful study of these occurrences and established clearly their glacial origin. Then one was found under similar conditions at Dowagiac, Michigan, in 1894, and another soon after near Cincinnati, Ohio. Within a few years past several small stones have been encountered by local gold-washers in the streams of Brown and Morgan counties, Indiana. These likewise are in or associated with the drift moraine, as doubtless was also the first one from this region, found, as above stated, as far back as 1830. A few small stones were also noted from this section in 1878 by the late Professor E. T. Cox, then state geologist, who first recognized their glacial derivation.

The number of diamonds accidentally found in these drift deposits—now some 25 or 30—shows that hundreds or even thousands of them must be lying

imbedded in the vast mass of morainal material that stretches across these states. From this fact it is evident that, wherever the source may be where they naturally occur, they must exist in considerable abundance. There must probably be, therefore, a diamond field in Canada that may be important if it can be found, although, from the small or very moderate size of the stones known, it cannot compare in any degree with the wonderful mines of South Africa. Under the direction of Doctor Ami a number of surveying parties along the line of the new Transcontinental railway, from Quebec to Winnipeg, are now on the lookout through all the region north of the Great lakes. But, on the other hand, the source may be farther north, in the unexplored wilderness of Ungawa. This is the view taken by Professor Hobbs, of Wisconsin, based on a careful study of the glacial striations left on the rocks, indicating the direction of ice-movement.

Some years ago there was for a time quite an interest in the suggestion of a possible diamond field in Elliott county, Kentucky. Certain igneous dikes in that region were found to resemble the rock in which the diamonds occur at Kimberley, in South Africa, and to contain some similar associated minerals, such as pyrope garnets ("Cape rubies"), etcetera; but careful examination failed to find any diamonds whatever. Recently the matter has been taken up again, and proposals have been made for extensive operations; but the fact remains that the first diamond has yet to be discovered, and there seems to be no warrant for undertaking such enterprises. W. C. Phelan, geologic aid of the U. S. Geological Survey, visited Elliott county, Kentucky, and spent considerable time in the preparation of an economic bulletin of the Canova quadrangle. Although he located a new dike, he was unsuccessful in finding the diamond itself. Notwithstanding that statements were current in the adjoining city of Grayson that diamonds had been found, yet he could not substantiate the finds.

Professor J. F. Kemp has located a similar dike, penetrating a coal vein in Fayette county, southwestern Pennsylvania, which he is describing at this meeting. Although the coal seam was entirely ruined by the penetration of the peridotite for a distance of some 20 feet, diamonds were not found. Professor Kemp at this meeting gives the petrographic depths of this occurrence on Middle run, a tributary of the Monongahela, in the Masontown quadrangle.

The paper was discussed by Robert Bell, A. C. Lane, J. M. Clarke, A. P. Coleman, H. M. Ami, A. P. Low, and J. F. Kemp.

The second paper was

IGNEOUS ROCKS OF THE EASTERN TOWNSHIPS OF QUEBEC

BY JOHN ALEXANDER DRESSER*

Remarks were made by G. O. Smith, with reply by the author. The paper is published as pages 497-522 of this volume.

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* Introduced by Dr F. D. Adams.

The third paper was

NEPHELINE SYENITE IN EASTERN ONTARIO

BY FRANK D. ADAMS

[*Abstract*]

The paper presents briefly some of the results of a detailed study of the occurrences of nepheline syenite in the townships of Monmouth, Glamorgan, and Methuen, in the province of Ontario. The character of the various differentiation products of the syenite magma are considered and the relation of the group to the granite bathylites and to the intrusive rocks of the region are discussed.

Remarks were made by A. C. Lane, R. A. Daly, and the author.

The fourth paper was

ORIGIN OF THE SUDBURY ORE BODIES

BY ALFRED E. BARLOW*

The paper was discussed by A. P. Coleman, J. F. Kemp, Robert Bell, A. C. Lane, and the author.

The next paper was presented by title:

BIBLIOGRAPHY OF THE GEOLOGY, MINERALOGY, AND PALEONTOLOGY OF BRAZIL

BY JOHN C. BRANNER

The following paper was read:

GEOLOGIC RECONNAISSANCE MAP OF ALASKA

BY ALFRED H. BROOKS

[*Abstract*]†

Contents

INTRODUCTION

Though geologic observations in Alaska can be said to have begun with the work of Stellar, the naturalist, who accompanied Bering on his ill-fated voyage in 1741, it is only in the past decade that systematic surveys have been madê,

* Introduced by H. M. Ami.

† The geologic maps and sections described in this abstract will appear as illustrations to a paper now in preparation entitled "The geography and geology of Alaska;" professional paper, U. S. Geological Survey, no. 45.

and as yet even reconnaissance mapping has been carried over only about one-fifth of the territory. Those familiar with the conditions met with by the geologist in this field need not be reminded that they are by no means favorable, and this will account for the rather meager results of some of the explorations. It appeared desirable to gather the very incomplete data and to attempt to outline the areas of some of the larger stratigraphic subdivisions, and this has been done on this map. The blanks in the map represent unsurveyed areas, yet the colored parts do not by any means indicate results of equal reliability. Areas like the Seward peninsula and the Copper River basin have been surveyed in considerable detail, while others, like the Kuskokwim and Tanana valleys, have been covered by only the most hurried reconnaissance work.

Stratigraphic Subdivisions and their Description

Ten stratigraphic subdivisions have been made; seven are sedimentary, two igneous, and one metamorphic. The so-called Pelly gneisses include gneisses and crystalline schists, as well as more massive intrusives, and possibly some sediments, which may in part be Archean, but very likely are, for the most part, deformed igneous rocks of a later date. A group of highly altered sediments, embracing many different formations, and probably chiefly Paleozoic, occupies the largest areas in the province. . The areas of Silurian are small, because it is only where fossils have been found that they could be differentiated from the other metamorphic terranes. The incomplete data has made it necessary to throw the Devonian and Carboniferous into one group. In most of the field it has been found impossible to make any subdivisions in the Paleozoic which are included in the metamorphic group.

Though all the subdivisions of the Mesozoic have been recognized in Alaska, the data are too fragmentary to permit of mapping them separately, and only two groups are recognized. The one embraces the Triassic and Jurassic, as well as the undifferentiated Mesozoic, and the second the Cretaceous.

The Tertiary, undifferentiated on the accompanying map, is almost entirely Eocene, for Miocene and Pliocene beds have been found at a few localities.

The Quaternary coloring has been extended to only the larger areas. Most of the rivers, except those that traverse the Coast range, are bordered by Pleistocene silts and gravels.

Of the intrusives the scale of the map permitted the representation of only the larger stocks, and even these have been omitted in the Archean areas where the gneisses and igneous rocks are not always easily differentiated. The distribution of the larger areas of the recent and Tertiary volcanics is shown throughout the regions surveyed.

It has been impossible to avoid the crazy-quilt effect due to the fragmentary data, yet some of the larger features of the geology are well illustrated. The general northwest trend of the western cordillera continues into Alaska to about the one hundred and forty-eighth meridian, where it bends abruptly to the west and southwest, as if to meet the northeastern extension of the Asiatic continent. That this is but a topographic reflecion of the dominant structural lines is well illustrated on this map, where you will note that there is a marked change of strike along the central meridian of Alaska. This line, in fact, marks the transition from the American to Asiatic trend of bed-rock structures.

Keeping this fact in mind, it will be possible to trace the stratigraphic subdivisions even on this very incomplete map.

A belt of metamorphic rocks striking parallel to the Pacific coastline has been traced northwestward through the panhandle and appears to find its extension in the Chugach mountains and in Prince William sound. In southeastern Alaska this belt includes various terranes, varying in age from Silurian or older to the Permian, with possibly some Triassic. Some Cretaceous beds are found infolded with it. It is cut off from the Paleozoic rocks of British Columbia by the broad belt of intrusives which make up the Coast range. At the westward extension of the belt Mesozoic beds overlap its inland margin. These Mesozoic beds are continued to the southwest, forming the country rock of the Alaska peninsula.

A second belt of metamorphic sediments is traceable through inland Alaska. This includes highly altered rocks, ranging from Silurian or older to Devonian. This zone ends in the Kuskokwim valley, where a broad belt of Cretaceous sediments mantels the metamorphic terranes. This belt is broken by an area of gneissoid rocks, but these, though first assigned to the Archean, are now believed to be largely altered intrusives. The metamorphic rocks appear again in the Seward peninsula and in northern Alaska and here constitute a third belt.

Little is known of the geology of the Rocky mountains of Alaska, except along the one hundred and fifty-first meridian, where Schrader's studies have shown them to be made up of closely folded Paleozoic terranes.

A belt of Permian beds, made up of slates and limestones, has been identified along the Seward margin of the Coast range and in the Copper River basin. Devonian beds are widely distributed, but the largest areas occur in the Yukon-Tanana region, where they are chiefly limestones and volcanics.

The Mesozoic period is represented by the Jurassic and Triassic rocks of the Copper River region, the Alaska range; also by two broad belts of Cretaceous rocks, one of which stretches northeastward from Bering sea to where it overlaps on the Paleozoic terranes near the southern front of the Rocky mountains, and the other stretches east and west across northern Alaska. The Tertiary period is represented chiefly by Eocene beds, which occur in broken areas along the seaward margins of the province. In the Yukon basin Eocene beds are found far inland, close to the international boundary. These are probably of lacustrine origin.

Intrusive rocks, among which granitic types dominate, are very abundant in southeastern Alaska. A broad belt of granitic rocks forms the backbone of the Alaska peninsula, and smaller rocks occur in the mountains to the northeast. All of these intrusives appear to be of Middle or Upper Jurassic age. The smaller masses of granite, so abundant in the Kuskokwim valley and found in the Seward peninsula, are probably of Tertiary age.

Recent and Tertiary volcanic rocks are widely distributed, and in the Alaska peninsula, Mount Wrangell region, and in the Bering sea littoral cover large areas.

The general stratigraphic succession in Alaska, so far as determined, is as follows: Some gneisses and crystalline schists have been provisionally referred to the basal member of the succession. These are succeeded by a great complex of metamorphic sediments, intruded by many igneous rocks whose age

and stratigraphic relations are often undetermined. Though these metamorphic beds have been subdivided into many formations, many of these are ill defined, and much more detailed evidence will be required before a definite statement as regards the succession can be made. Some of the lower members of this great complex have yielded Ordovician and Silurian fossils, while in some of the upper beds Devonian fossils have been found. In the Yukon basin and in the panhandle there appears to be an unconformity near the base of the Devonian, below which the rocks are much more highly metamorphosed. The older and more crystalline sediments are probably Silurian, Ordovician, Cambrian, or possibly pre-Cambrian. The metamorphosed clastics of southeastern Alaska include Devonian and Carboniferous, and elsewhere in the province Devonian and Carboniferous terranes have been found.

Triassic beds have thus far been recognized only in the Copper River basin and in southwestern Alaska, while the Jurassic occurs in this district and also at cape Lisburne, in northern Alaska. The lower Cretaceous is widely distributed and includes the youngest beds known to have suffered any considerable metamorphism. It appears that the unconformity separating the upper and lower Cretaceous horizons was of considerable extent. The upper Cretaceous occurs in the Yukon basin, in southwestern and southeastern Alaska, as well as north of the Rockies.

Of the Tertiary horizons the Eocene coal-bearing beds are the only ones which have been found widely distributed, and these occupy no considerable areas. Miocene and Pliocene beds appear to have relatively small development. The Pleistocene is represented throughout the province by gravels, sands, and silts, and in the regions which have been occupied by ice by various forms of glacial deposits.

Correlation Table.

On the table I have indicated the stratigraphic succession in four of the best known districts and suggested certain correlations between them.

In southeastern Alaska the basal member consists of phyllites and crystalline limestones, in part at least of Silurian age. These are succeeded by crystalline limestones and slates of Middle Devonian age. The next horizon is a chert and limestone series, carrying lower Carboniferous fauna and resting unconformably on the older rocks. These are succeeded by a complex of phyllites and greenstones, with some limestones, in part at least of Permian age. A heavy conglomerate series, resting unconformably on the Paleozoic rocks, represents the oldest Mesozoic of this province, and is probably Cretaceous. These are unconformably overlaid by a soft sandstone and shale series, in part of upper Cretaceous, in part of Eocene age.

The extensive basalt flows have been provisionally assigned to the Miocene, while the Pleistocene is represented by silts, sands, and gravels, as well as by glacial drift.

Highly metamorphosed schists and limestones form the oldest sediments of the Copper River region, and are of pre-Devonian age. These are unconformably succeeded by a massive conglomerate and slate series, associated with volcanic rocks which have been provisionally referred to the Devonian. The Carboniferous is represented by a lower member, made up of heavy crystalline limestone, and an upper consisting of many thousand feet of limestones, shales, and volcanics. These are overlaid by a volcanic and limestone

group of Triassic age, and on these the Kennicott formation rests unconformably. The Tertiary in this district is represented by some small areas of lignite-bearing Eocene sandstone, and by a great thickness of volcanics, the latter merging with those of recent date.

The succession in the Yukon region has not yet been well determined. It appears that the so-called Birch Creek schists form the oldest sediments, and these may rest on an older gneissic complex. Within the schistose series occur beds of crystalline limestone. In some areas at least a massive limestone appears to form a higher member of the metamorphic series, but this is not definitely established. A great thickness of greenstones, with which are intercalated some Middle Devonian limestones, form the next higher group, resting unconformably on the older and more highly metamorphosed rocks. In some parts of the basin a massive Carboniferous limestone forms the next higher member of the succession.

The Lower Cretaceous is represented by some calcareous sandstones and black slates. As in southeastern Alaska, the upper Cretaceous and Eocene appear to be represented by an unbroken succession of sandstones and shales. A formation made up of sands, clays, and gravels has been provisionally referred to the Pliocene.

In northern Alaska Schrader found a series of schists forming the basal member of the succession, and this overlaid by a massive crystalline limestone. The latter, on the evidence of a few obscure fossils, has been tentatively assigned to the Silurian. Both Devonian and Carboniferous beds have been found in this region, but the stratigraphic succession is obscure.

Lower Cretaceous rocks overlap the Paleozoics, both north and south of the range, and on the Arctic slope are succeeded unconformably by Eocene beds. These in turn are overlaid by Pliocene silts.

Structure

The parallelism between the bed-rock structures, the mountain ranges, and the shoreline has been pointed out. In southeastern Alaska the dominant structures trend northwest and then, near the one hundred and fifty-first meridian, swing west and south.

Three sections are presented to indicate some of the larger structural features. The first reaches from Controller bay, through the Chugach and Wrangell mountains, to the international boundary. On the coast of the section are indicated the closely folded Tertiary beds, resting unconformably on the metamorphic sediments which make up the Chugach mountains. These latter, which are probably in part Paleozoic, are intensely deformed. They are separated by a fault from the broad syncline which makes up the Wrangell mountains. The basal beds in this syncline are Carboniferous, which are overlaid unconformably by Mesozoic sediments, and these in turn are capped by Tertiary and recent lavas. Another fault cuts off the northern area of the syncline from a broad belt of closely folded Mesozoic sediments. North of the Pleistocene silts, which floor the Tanana valley, the section traverses a belt of schists with which are closely associated some gneissic rocks. A section across the Alaskan range indicates a broad synclinorium of Mesozoic rocks (chiefly Jurassic) resting unconformably on Devonian limestone on the west, which in turn rests on phyllites and cherts, which have yielded some Ordovician

fossils. The section in northern Alaska indicates two anticlinal axes, with sharp flexures and faulting, separated by a broad syncline. In the southern anticline the basal schists and a Silurian limestone are exposed. The structure in the northern anticline is complicated by extensive faults. These Paleozoic rocks are succeeded by gently folded Cretaceous rocks on both flanks of the range. On the north the horizontal Tertiary sediments rest on the Cretaceous beds.

Remarks were made by T. A. Jaggar, a visitor.

The last paper of the day was

COAST RANGE OF SOUTHEASTERN ALASKA

BY FRED EUGENE WRIGHT

Session of Wednesday Evening, December 27

At 8.30 o'clock the Society met in formal session in the parlor of the Russell House, and the President of the Society, Raphael Pumpelly, delivered an address entitled

INTERDEPENDENT EVOLUTION OF OASES AND CIVILIZATIONS

The address is printed as pages 637-670 of this volume.

Following the presidential address a "smoker" was given by the Logan Club of Ottawa to the Fellows of the Society.

Session of Thursday, December 28

The Society met at 10.00 o'clock a m, President Pumpelly in the chair.

The Council report was taken from the table and was adopted without debate.

The report of the Photograph Committee was presented, as follows:

SIXTEENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

During the year 1905 there has been but little change in the collection of photographs belonging to the Society. No new views have been obtained, but through the kindness of the Director of the Geological Survey about 100 old prints have been replaced by new ones, which are printed in a superior manner and mounted on muslin. By this means the bulk of the collection has been considerably diminished.

The photographs are now stored in glass cases in my office, in the building of the Geological Survey, Washington, convenient for reference. Several members of the Society have obtained prints for use in reports and text books, and it is believed that there ought to be a very much wider use of the photographs for this purpose. It is expected that during the coming year a large number of new photographs will be added to the collection, selected from the vast number of views which have been taken by members of the Geological Survey during the past few years. Contributions for the collection are desired, but care should be taken that they are views of general interest and illustrate geologic phenomena rather than scenery. A high technical standard is also required.

Respectfully submitted.

N. H. DARTON,
Committee.

The report was adopted, and the usual appropriation of $15 for the use of the committee was voted.

RESOLUTION CONCERNING INTERNATIONAL GEOLOGICAL CONGRESS

The following resolution was presented from the Council and adopted:

"*Resolved*, That the Geological Society of America gives expression to the sincere feeling that it would be highly appropriate and desirable to hold the International Geological Congress in Ottawa in 1909."

Several announcements were made: By S. F. Emmons and the Secretary, relating to the meeting of the International Geological Congress in Mexico in September, 1906; by H. M. Ami, with reference to the evening program; by J. F. Kemp, with reference to the annual dinner, and by the Secretary, stating that a local photographer would take a photograph of the Fellows at the close of the morning session.

The scientific program was taken up, and the first paper read was

GEOLOGICAL SECTION ACROSS THE CORDILLERA ON THE INTERNATIONAL BOUNDARY LINE (49TH PARALLEL)

BY REGINALD A. DALY

Remarks were made by A. H. Brooks and G. O. Smith.

The second paper was by the same author, and entitled

THE OKANAGAN COMPOSITE BATHOLITH OF THE CASCADE MOUNTAIN SYSTEM

BY REGINALD A. DALY

The paper was discussed by A. C. Lane, A. P. Coleman, J. D. Irving,

J. F. Kemp, F. E. Wright, G. O. Smith, R. W. Brock, T. A. Jaggar (a visitor), and the author.

The paper is printed as pages 329-376 of this volume.

The third and last paper of the morning session was

RECENT CHANGES OF LEVEL IN THE YAKUTAT BAY REGION, ALASKA

BY RALPH S. TARR AND LAWRENCE MARTIN

Remarks were made by A. E. Coste (a visitor), W. H. Sherzer, and A. H. Brooks.

The paper is printed as pages 29-64 of this volume.

The Society adjourned for the noon recess, and reconvened at 2.15 o'clock p m.

Remarks were made by T. L. Walker relating to the place of meeting of the International Geological Congress in 1909, and inquiring as to the purport and effect of the resolution adopted at the morning session.

The scientific program was resumed, and the first paper was the following:

OBSERVATIONS IN SOUTH AFRICA

BY W. M. DAVIS

Remarks were made by David White, with reply by the author. The paper is printed as pages 377-450 of this volume.

The second paper was

DRUMLIN STRUCTURE AND ORIGIN *

BY H. L. FAIRCHILD

[*Abstract*]

Contents

INTRODUCTION

The paper was a brief description, aided by maps and lantern slides, of important drumlin features found in central New York, and a concise statement of conclusions relating to the origin of drumlins.

* By permission of the New York State Geologist.

Distribution

Typical drumlins or drumlin ridges are the most emphatic of a variety of forms produced by the rubbing action of the ground-contact ice under thrustal motion. On the one hand these forms shade off into indefinite flutings or moldings of the drift, and on the other hand are represented by scoured or rounded rock hills (drumloids). The requisite conditions for production of distinct drumlins do not seem to have been commonly fulfilled, as vast areas of glaciated territory seem never to have been subjected to the drumlinizing movement of the ground-contact ice.

The land surface included in the drumlin area of New York is a belt about 35 miles wide, bordering the south side of lake Ontario, and about 140 miles long (from Niagara river to Syracuse), with a total area of about 5,000 square miles. At least half of this area carries numerous well developed drumlins. An eastward extension of the area swings around the east end of lake Ontario as a belt 5 to 10 miles wide, reaching past Watertown into the Saint Lawrence valley.

The New York drumlin area probably includes not less than 10,000 drumlin crests, of which at least 6,000 are indicated on the topographic sheets. On the 216 square miles of the Palmyra quadrangle an actual count shows 955 indicated on the map. Probably hundreds of minor ridges are beneath the recognition of the contour lines, with 20 feet interval.

Orientation

The longer axis of the drumlins indicate the direction of the latest vigorous movement of the ice-sheet in their locality, and their variant directions throughout the New York area prove a radial or spreading flow of the ice-mass during the stage of waning which is represented by the drumlin formation. The angular directions cover nearly a half circle. East of lake Ontario they point east—that is, they were shaped by a movement of the ice from the west. Passing westward around the south side of Ontario the directions of the drumlins gradually shift to southeast, then to south, and in western New York to southwest.

The axial direction is not always uniform along the same meridian, but records any change in the direction of the ice movement due to the topographic control over the waning edge of the ice-sheet in its different positions. A confirmation of this genetic relation between drumlin attitude and ice-flow direction is found in the Pulaski region. As we pass eastward around Mexico bay we find the direction toward which the drumlins point changes from southeast to east; but passing on 10 miles to the north we find the drumlins pointing southwest, or at right angles to those near Mexico. These varied directions represent ice-flow movement during successive stages of the waning ice body.

Relation to Topography and Rock Strata

The most massive development of drumlins is on the low Ontario plain north of the Finger lakes and mainly under 500 feet altitude. They are comparatively absent on the higher ground which faced toward the ice body. This dominant drumlin area is underlain by the Cayugan (Salina), Niagaran, and Oswegan

(Medina) strata, which consist of about 3,000 feet of shale, between 200 and 300 feet of limestone, and 400 or 500 feet of sandstone. The predominance of shale in the outcrops from whence the ice obtained its rock debris supplied a burden of unusually clayey and adhesive drift, and it seems probable that the adhesive and plastic character of the subglacial drift was a contributing factor to the remarkable development of close-set drumlins.

Form and Size

The several types may be distinguished as the mammilla or dome, the oval, the slender oval or short ridge, and the linear or attenuated ridge. The two latter forms include the great majority of the New York drumlins. The dome form is rare in New York. It is an important fact that the different types are not intermingled. Of the ridge form there are two extreme varieties. A large form constitutes broad, low swells or rolls, which may not be recognized as of drumlin nature and are often overlooked by the map contours. These low, broad moldings of the till are the common form over the surface of the Niagara-Genesee prairie. The small variety of the long ridges is abundantly displayed in the Clyde-Savannah district, where between the major drumlins or on their sides lie a secondary or minor order of ridges, often not larger than a railway embankment. These small, attenuated ridges characterize the frontal border of the drumlin belt when faced by a moraine.

The limit to the height of drumlins seems to be about 180 to 200 feet. At some point in the upbuilding process the growth is antagonized by an eroding or leveling tendency and a balance is struck between the opposing forces which limits extreme height, and which apparently results in the production of multiple ridges of moderate size instead of one huge ridge.

Composition and Structure

The New York drumlins are composed of compact till. Only two instances have been found of water-laid drift distinctly within the drumlin mass. The deeper layers are more compact than ordinary sheet till and the included stones of all sizes are more generally abraded.

Along the south shore of lake Ontario a score of drumlins, some of large size, are dissected to their core by wave erosion. More than half of the cliffs show undoubted concentric foliation, and in several it is surprisingly distinct. In cross-section view the layers near the base are only slightly arched, and the arching increases toward the top, where the layers are parallel with the profile. In the different sections it is found that the exposed foliation has the directions corresponding to concentric layers. The constructional origin of these drumlins is beyond question.

Between Palmyra and Syracuse the foundations of the drumlins are Salina shale, the soft red and green beds known as Vernon. Some of the low ridges are probably composed entirely of the shale, with a veneer of drift. On the parallel of Baldwinsville all the drumlin-like forms east of Seneca river are composed of the red shale and are not drumlins, but rocdrumlins.* The hills of Vernon shale (hardened clays, without evident bedding, and easily decomposed) which stood within the zone of drumlin formation, in conflict with the rubbing ice, were more easily shaped into the drumlin form than other rocks;

* The Celtic word for rock is used as a prefix.

but when given that shape they resisted the ice impact better than harder rocks, as the product of the ice rubbing was a lubricant and plastic paste, essentially like clayey till in its mechanical properties. The shale hills were at first compliant, and then resistant to the ice. They became drumlins in effect, though not in origin, being erosional forms, not constructional.

The shaping of hills of the softest rock instead of leveling them is an evidence of erosional weakness of the ice in the drumlin belt. Vigorous abrasion of hard rocks would not be consistent with drumlins in the same locality.

Relation to Moraines and to glacial Lakes

During the stage of ice waning represented by the dominant drumlin area the ice-front was swept by vigorous rivers on the higher ground and was faced by lakes on the lowest ground. The drumlins reach up to the north side of the drainage channels in good strength, but they fade out into attenuated forms in the areas where the ice-front was not swept by streams, and where consequently the drumlin tracts are fronted by moraines. These moraines represent only the superglacial and higher englacial drift, carried to and dropped at the extreme edge of the ice, while the drumlins were forming at the same time from the subglacial and lower englacial drift beneath the ice-sheet, in the rear of the moraine.

Theoretically the moraines should be weak where the drift was largely left in drumlin form, and the facts seem in accord.

Formation; Mechanics

The idea that drumlins represent overridden moraines, or are erosional in origin, may be true of some drumlins, but certainly is not true of the majority of New York drumlins, which were constructed or built up by a plastering-on process.

In the mechanics of drumlin construction three sets of factors are recognized: (*a*) factors pertaining to the ice itself; (*b*) those relating to the drumlin-forming drift; (*c*) the external influences of topography and climate.

The dynamic factors pertaining to the ice body (*a*) include: (1) vertical pressure; (2) horizontal pressure; (3) vigor and velocity of flow; (4) differential flow; (5) plasticity.

The factors relating to the drift (*b*) are: (1) volume of the drift; (2) position of the drift; (3) quality of the drift.

The factors of external control (*c*) are: (1) general land slope; (2) minor features of the topography; (3) temperature and water supply.

The building up of the drumlins is coincident with the rubbing off or shaping effect. As masses, the hills were built by accretion of the drift, but the convex forms are due to the erosional factor. The whole process may be compared to the work of the sculptor on a clay model—a plastering on and rubbing away. The accretion is due to the greater friction between clay and clay than between clay and ice. The hills of accretionary drift resisted the ice impact and rasping effect in the same manner as did the hills of shale. The form possessed by both classes of hills is that which opposed the greatest resistance to removal by the ice or the least resistance to the overriding movement of the ice.

The drumlins were shaped by the sliding movement of the lowest ice, that in

contact with the land surface. This fact implies that the whole thickness of the ice-sheet participated in the motion. Such motion was not due to gravitational stress on the ice over the drumlin area, but to effective thrust on the marginal ice by the gravitational pressure of the rearward mass. As the margin of the ice-sheet thinned by ablation, there came a time when the drift-loaded ice in contact with the ground was subjected to less vertical pressure and to relatively greater horizontal pressure by the deep ice in the rear, and was pushed forward bodily. In this fact is believed to lie the key to drumlin formation.

The combination of conditions requisite for effective thrust movement over a belt of country and for considerable time may be rare, and it does not seem so strange that drumlins are uncommon features when we consider the variety of dynamic factors which are concerned directly or indirectly in drumlin formation.

It may be assumed that wherever the ground-contact ice had a vigorous movement of some duration it should be indicated by the molding of the ground surface, specially where this is comparatively level and composed of drift or soft rocks. The absence of drumlinizing of the drift surface may be assumed as indicating lack of movement of the ground-contact ice. Well marked drumlins are not found on the high ground east of Seneca lake, nor on the low ground east of Syracuse. The explanation seems to lie in the relationship of the larger topography to the movement of the ice-sheet. When the glacier was deep over the Finger Lakes region the bottom of the ice in the drumlin area was probably quiescent and served as a bridge over which the upper ice moved, the repose of the lower ice being due to the opposing land slope and to the large volume of drift which the ice had incorporated. Over the nearly level area north of the Finger lakes the waning of the ice-sheet finally brought the ground-contact ice under horizontal thrust; but in the adjacent district of low ground northeast and east of Syracuse we have an example of the non-motion of the bottom ice. The almost bare hills of soft Vernon shales in the district of Canastota have not been subject to rubbing action of ice in any direction. The surface would have been sensitive to any ice movement, but the deeply buried ice was stagnant and the shallow ice was not subjected to push by any thicker ice on the northward.

In the balancing and adjustment of the several dynamic factors in the drift-burdened ice, the two opposing forces of rigidity and plasticity seem to be the most important. The existence of the drumlins implies that the depth of the ice and the vertical pressure were so moderate as to allow the plastic ice to override and to adapt itself to the hills, while at the same time the whole sheet of ice was sufficiently rigid to accept horizontal thrust.

The paper was discussed by R. S. Tarr, I. C. Russell, A. P. Coleman, W. M. Davis, and W. H. Sherzer. The full paper, with ample illustrations, will be printed as a bulletin of the New York State Museum.

The third paper was

DRUMLINS OF MICHIGAN

BY ISRAEL C. RUSSELL

[*Abstract*]

Studies of a drumlin area in the northern peninsula of Michigan, a brief report concerning which was presented at the last winter meeting of this Society, have been continued and additional facts obtained that strengthen the conclusion previously advanced in reference to the drumlins referred to having been produced by ice erosion of a previously deposited till sheet.

A contour map of a characteristic group of drumlins was exhibited, which illustrated one of the several classes of irregularities presented by the drumlins of Michigan. In certain instances they depart from the normal shape and have a straight, steep slope on one side. Drumlins showing this asymmetry are thought to have been complete and symmetric in form at one time, but later were partially removed by ice erosion. In the case of one of the examples represented on the map referred to, about one-half of a drumlin, cut parallel with its longer axis, appears to have been removed.

Attention will also be invited to the smooth surface concave troughs which occur between adjacent drumlins, and in numerous instances are as characteristic features of drumlin topography as the similarly smooth, convex hills they separate. Such "drumlin troughs" are thought to furnish criteria for recognizing the effects of ice erosion in moraine and till covered regions, where the correlative convexities are absent or but poorly defined.

Certain of the drumlins of Michigan are composed of sandy till which is without foliation, while other examples consist of definitely laminated clayey till. The foliation appears to be due to pressure, and is present or absent according to the nature of the material.

The fourth paper was

THE LEFROY, A PARASITIC GLACIER

BY WILLIAM H. SHERZER

[*Abstract*]

At the head of the Lake Louise valley, Canadian Rockies, lies the Victoria glacier, which receives from the southeast a tributary somewhat over a mile in length and from one-third to one-half mile in width. This tributary proves to be double, the Lefroy being superposed on the Mitre and moving across it at right angles. The parasitic Lefroy is formed from the ice and snow avalanched from the eastern shoulder of mount Lefroy, and carries across the Mitre the ground morainic material manufactured beneath the hanging glacier on mount Lefroy. This material is dumped on the eastern margin of the Mitre glacier, by which it is delivered to the Victoria as though it had come from mount Aberdeen. The discovery of this relation of the Lefroy to the Mitre glacier explains the direction of the dirt zones, the presence of the ground morainic material in the right lateral of the Victoria, and its arrange-

ment in ridges parallel with the side of the glacier. It shows, further, that two glaciers may occupy the same region at the same time, nourished differently, with different structure, direction, and rate of motion, and accomplishing different geological results.

The full paper is published in the reports of the Smithsonian Institution.

The fifth paper was by the same author, entitled

ORIGIN OF THE MASSIVE BLOCK MORAINES IN THE CANADIAN ROCKIES AND SELKIRKS

BY WILLIAM H. SHERZER

[*Abstract*]

In the five most accessible valleys along the line of the Canadian Pacific railway, the heads of which are still occupied by glaciers, there occurs a peculiar type of moraine, composed of massive angular blocks, remarkable for the scarcity or absence of fine material. They differ markedly from the moraines of older date and also from those of more recent formation. In the case of three of the glaciers there are two such moraines, and in the other two the double character is indicated. The blocks composing them were carried either on or in the ice and were not pushed along ahead or beneath it. They show no signs of water action by which the finer materials could have been removed. The various possible theories of their origin have been considered, and the conclusion reached that a double seismic disturbance affected the entire region, by which the glaciers became loaded with coarse fragments of the overtowering cliffs. If the theory proves sound we have a means of correlating the position of the main trunk glaciers, which were favorably situated, for determining their actual and relative amount of recession since the time of the disturbances.

Remarks were made by R. S. Tarr. The paper is published in full in the reports of the Smithsonian Institution.

The sixth paper was read by title:

GLACIATION OF MANHATTAN ISLAND, NEW YORK

BY ALEXIS A. JULIEN

The character and extent of plucking action by the continental glacier upon the crystalline schists are shown by jagged, broken surfaces covered by till, fractured slabs often hardly displaced, and angular transported boulders. Semi-lunar grooves are found on the limestone, and the pitting of surfaces on rounded hummocks are referred to the same action. Abundant channels and troughs are attributed to erosion by subglacial running water, connected with moulins through crevasses in the ice-sheet. A new hypothesis is advanced to account for the pot-holes found in vicinity of the island. A sudden bending southward of the directions of glacial furrows, their southward curvature,

and peculiar asymmetric form, are presented in evidence of a strong slope of the general surface to south-southwest at the time of its subsidence during the glacial movement. The undercutting of joint planes facing the northeast has created an unusual feature in topography.

The seventh and last paper of the day was read by title:

GLACIAL PHENOMENA OF THE SAN JUAN MOUNTAINS, COLORADO

BY ERNEST HOWE AND WHITMAN CROSS

The paper is printed as pages 251-274 of this volume.

Session of Thursday Evening, December 28

In the assembly hall of the Normal School, at 8.15 o'clock, a public lecture, complimentary to the citizens of Ottawa, was given by Dr John M. Clarke, State Geologist and Director of Science, New York State; the subject was

CONSERVATION OF NIAGARA FALLS

Session of Friday, December 29

The Society met at 9.30 o'clock a m, President Pumpelly in the chair.

The following resolution, offered by A. C. Lane, was passed by majority vote, after discussion:

"*Resolved*, That the Council, if after consideration they find it wise and feasible, employ an expert stenographer to report the discussions in the meetings of the Society, such parts thereof to be published after revision by the speakers as the Committee on Publication and the speakers may deem wise."

AUDITING COMMITTEE'S REPORT

The Auditing Committee reported that the accounts of the Treasurer had been found correct, and the report was adopted.

Professor I. C. Russell suggested that the preparation of a geologic map of North America would be appropriate work for the International Geological Congress. It was voted to appoint a committee to take the matter in hand. The President subsequently named as such special committee I. C. Russell, C. W. Hayes, F. D. Adams, and J. G. Aguilera.

The Secretary announced some details of the arrangements for the annual dinner, to occur in the evening, and the program of papers was taken up.

The first paper presented was

GEOLOGY OF OTTAWA AND ITS ENVIRONS

BY H. M. AMI

[Abstract]

For the visiting geologists a series of lantern views were projected, showing the geologic features about Ottawa; the stratigraphic succession, Archean crystallines, Potsdam, Beekmantown, Chazy, Birdseye, Black River, Trenton, Utica, Lorraine, Medina, and the Pleistocene deposits. The faunas of the sedimentaries were briefly considered.

The second paper was

NOTES ON ARCTIC GEOLOGY

BY ALBERT P. LOW

Remarks were made by W. M. Davis and the author.

The third paper was

OLDEST PRE-CAMBRIAN ROCKS

BY C. K. LEITH

The paper was discussed by A. C. Lane, A. P. Coleman, and Arthur Keith. It is published in a bulletin of the U. S. Geological Survey.

The Society adjourned for the noon recess, and reconvened at 2.30 o'clock p m, with S. F. Emmons in the chair.

The first paper of the afternoon session was

GLACIAL HISTORY OF NANTUCKET AND CAPE COD

BY J. H. WILSON*

[Abstract]

Late Wisconsin ice-sheet occupied this region with two distinct lobes: First. Nantucket lobe, with three stages: *a*, Nantucket stage; *b*, Cape Cod stage; *c*, Cape Cod Lake stage. Second. Long Island lobe, with two stages: *a*, Marthas Vineyard–Block Island stage; *b*, Elizabeth Islands–Fishers Island stage. The Nantucket lobe is shown to have come probably from as far as Newfoundland, and to have extended at least 150 miles out to sea. Reasons for this are numerous. Especially notable are: character of transported material, evidences of glacial erosion over the area concerned, direction of motion of ice, and character of the interlobate moraine.

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* Introduced by A. W. Grabau.

The following topics are discussed in detail:

Nantucket; preglacial formations; interglacial formations; the Sankaty Head deposits; the late Wisconsin ice-sheet; the four zones (marginal): 1, kame hills; 2, fosse; 3, ice-contact slope, and, 4, apron plain. Detailed description of these and tracing of ice-contact slope; peculiarities of Miacomet valley; postglacial deposits and changes in elevation; associated phenomena of Marthas Vineyard and Block island.

Upper cape Cod and associated phenomena of Elizabeth islands and Fishers island.

Cape Cod lake (third stage of Nantucket lobe); lower cape Cod; the sand plains of Eastham, Wellfleet, Highlands, and Truro; the morainal dam; the cols or outlets, the three stages of the lake: 1, Wellfleet; 2, Highlands; 3, Truro; summary.

The paper has been published as volume i, Geological Series, Columbia University Press.

Remarks were made by A. C. Lane.

The second paper was

ICE BORNE SEDIMENTS IN MINAS BASIN

BY J. A. BANCROFT*

In absence of the author the following paper was presented in abstract by W. M. Davis:

GEOLOGY OF THE LOWER COLORADO RIVER

BY WILLIS T. LEE

Comments were made by Professor Davis. The paper is printed as pages 275-284 of this volume.

The next paper was

CRETACEOUS SECTION IN THE MOOSE MOUNTAINS DISTRICTS, SOUTHERN ALBERTA

BY D. B. DOWLING†

The paper is printed as pages 295-302 of this volume.

The following paper was presented:

GEOLOGY AND PALEONTOLOGY OF NORTHERN CANADA

BY H. M. AMI

The paper contains notes bearing on the collection recently obtained by Commander A. P. Low, of the Geological Survey of Canada, in northern Canada,

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* Introduced by F. D. Adams.

† Introduced by H. M. Ami.

during 1903 and 1904; the faunas determined and the geological horizons to which they are referable, together with correlations of results in previous explorations. The paper is illustrated with specimens from Beechy island, Lancaster sound, and other localities.

The following paper was read, in absence of the author, by J. F. Kemp:

TYPES OF SEDIMENTARY OVERLAP

BY A. W. GRABAU

Remarks were made by H. M. Ami and C. W. Hayes. The paper is printed as pages 567-636 of this volume.

The next paper was

*GILBERT GULF (MARINE WATERS IN ONTARIO BASIN)**

BY H. L. FAIRCHILD

That all the shorelines of the extinct glacial lakes in the Laurentian basin have now an upward slant in northward directions is a well known fact of observation. Another long recognized fact is the occurrence of marine deposits of Pleistocene age in the Champlain and Ottawa valleys, a whale skeleton being found as far inland as Welchs siding (near Smiths Falls), some 30 miles northwest of Ogdensburg. If the tilt is due to northward uplift and not to southward downthrow, it follows that the altitude of the land surface at any point was, during the life of those lakes, as much below the present height as the amount of differential uplift. From the above facts and principle it has long been recognized that the carrying down of the deformed planes of the ancient lakes to horizontality would carry the head of the Saint Lawrence valley far below sealevel. The conclusion follows that when the Labradorian ice-sheet melted away from the upper Saint Lawrence valley the sealevel waters spread westward through the straits at the Thousand islands and occupied the Ontario basin; and the studies of Gilbert, Coleman, Spencer, Taylor, and others seem to have made the theoretical conclusion a certainty.

The sequence of events would seem to have been as follows: While the ice-body was blocking the upper Saint Lawrence valley the waters in the Ontario basin were held up to the level of Rome and forced to outflow to the Mohawk-Hudson; but when the ice waned on the north slope of the Adirondacks and opened passes lower in altitude than the Rome outlet, the Ontario waters (lake Iroquois) were diverted to the northern escape and flowed out to the Champlain valley. The rivers draining the sub-Iroquois waters must have washed the ice-front, and must have shifted their position to lower and lower levels as the ice-front backed away on the north-facing slope. The existence of such ice-border or proglacial river channels on the north and northeast flanks of the Adirondack massif was determined by Doctor Gilbert some years ago, and the

* By permission of the New York State Geologist.

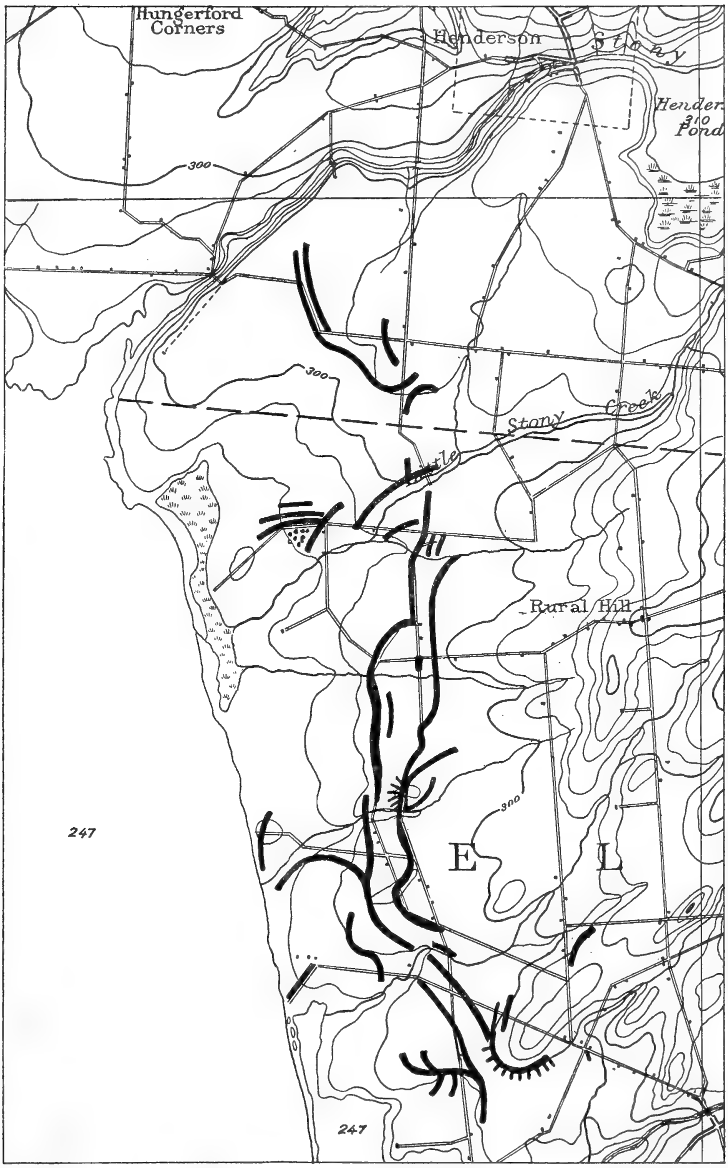


FIGURE 1.—*Gilbert Gulf Shore Features.*

Cliffs, bars, and spits east of lake Ontario, south of Henderson. Part of the Sacketts Harbor topographic sheet somewhat reduced.

features have been described by Professor Woodworth for the Mooers quadrangle.*

Doctor Gilbert had also noted shore phenomena, cliffs and bars, in the district east of lake Ontario which he regarded as the work of the sealevel waters. These were subsequently seen by the writer, and in the summer of 1905 these supposed marine features were traced with some care from a point on the Ontario shore a mile northeast of the hamlet Texas, and about 14 miles northeast of Oswego, northward to near Henderson village, through a stretch of about 21 miles.

Throughout this district the cliffs, spits, and bars are well developed, as shown in figures 1 and 2. The approximate altitudes of the features are indicated by the map contours. The spit near Texas is about 16 feet over the lake, or 262 feet above tide. The highest bars in the region of Henderson are from 310 feet to 320 feet altitude. The lower may not represent the full height of the water surface, as they were built out some distance from the shoreline and are not very coarse material. The spit at Texas is very coarse material and probably is a storm beach; but, taking the features as they lie, the rise of 53 $\pm$ feet in 21 miles of right line distance shows a deformation of at least 2.5 feet per mile.

The bars occur at various levels, beneath the highest one, down to the present lake. This is to be expected of the work of marine waters here, because the change of level in relation to the land surface was due to continental uplift, which was a process sufficiently slow to allow effective wave work at all inferior altitudes. It might not unreasonably be expected that shore phenomena would be found at levels intermediate between the Iroquois beach and these supposed marine beaches, which should represent the long pauses in the lowering of the sub-Iroquois waters while the overflow was cutting the rock channels near the north border of the State; but such features do not occur, though wave-swept areas of limestone are found.† In the beaches under discussion we apparently have the effects of wave-work at planes of water level much more enduring than was possessed by the sub-Iroquois waters with shifting outlets.

The positive proof that these beaches were made at sealevel would be the finding within them of marine fossils. Casual search has not yet discovered any fossils of either fresh or salt water. However, the absence of fossils would not be conclusive; and even the presence of fresh-water shells might not be positive proof against sealevel attitude, as it might be held that the long and narrow Saint Lawrence strait and the outflow of copious glacial waters might prohibit the inflow of salt water. It seems likely, however, that the strait was sufficiently deep (more than 150 over the present river surface) and sufficiently wide (many miles after the ice-front backed away) to allow the waters to become at least brackish.

Whether the waters which produced these beaches were open to the sea or not, they deserve a distinctive name. They are neither Iroquois nor Ontario.

* J. B. Woodworth: Pleistocene geology of the Mooers quadrangle. Bulletin 83 (geology 7), New York State Museum, 1905.

† In the falling of the glacial waters in central New York from the Warren to the Iroquois level, or from 880 to 440 feet, only one pause has been found of sufficient endurance to produce conspicuous shoreline features, that of lake Dana at 700 feet, although capacious rock canyons were cut in the district of Syracuse.

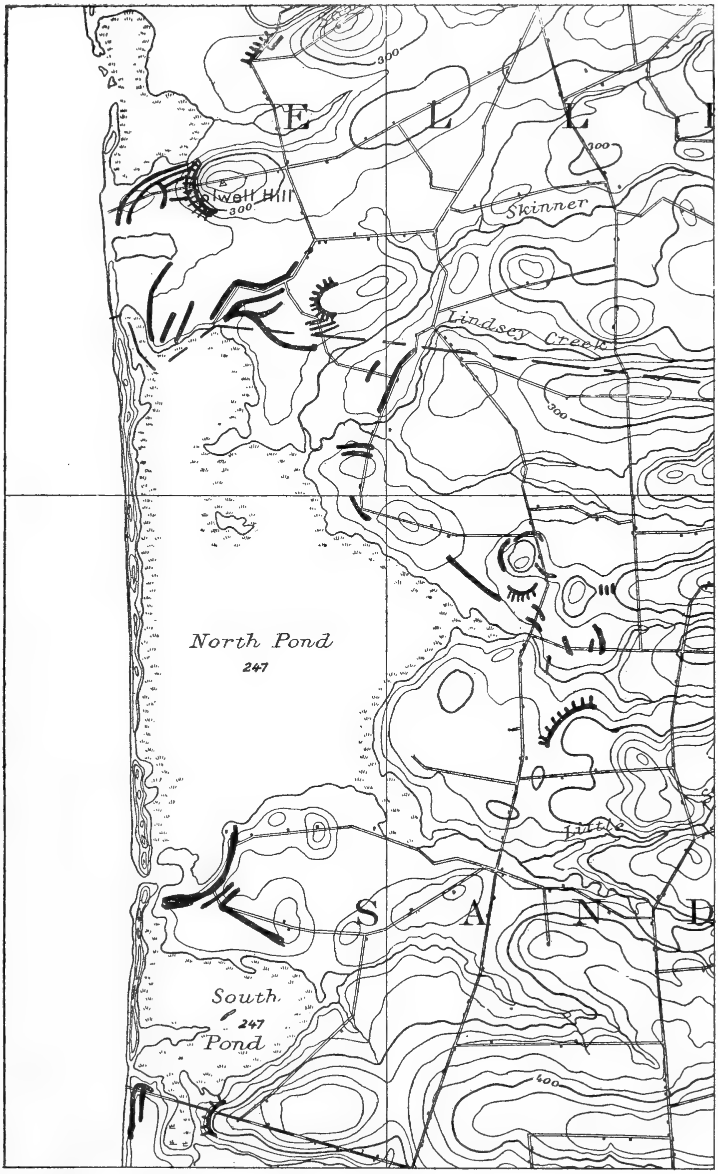


FIGURE 2.—*Gilbert Gulf Shore Features.*

Cliffs and bars east of lake Ontario, west of Mannsville and Sandy creek. Part of the Pulaski topographic sheet somewhat reduced.

The sealevel attitude is so nearly a certainty that the term "gulf" seems appropriate, and the water is named after Doctor Grove Karl Gilbert, who was the first geologist to note the beaches and appreciate their significance, and who has had special interest in and knowledge of the Pleistocene features in the Ontario basin.

After mapping the shore features shown in figures 1 and 2 the plane of the water surface was projected northward, and it was calculated that it would lie on the highest ground near Clayton, and specially on a hill 4 miles southwest of the village. A visit was made to the locality and the shore features found precisely as expected. These are shown in figure 3. The "hogback" hill carries remarkably strong spits and cliffs, and good bars at corresponding levels occur on the east. If the contour of 440 feet on the hill summit is correct, then the shore features have an altitude of about 400 feet. Good bars are found 3 miles south of Clayton on the 400-foot contour. Two miles southwest of the village, on the road to the "hogback" hill, is a hill by the Tiernan corners with good spits and cliffs at about 350 to 360 feet, by the map, and west of the corners is a gravel plain more than a mile long with map altitude of 380 feet.

On the supposition that the highest shore features represent the work of marine waters, we conclude that the total uplift of the land at Clayton has been 400 feet since the initiation of the Gilbert gulf. Taking the altitude of the water plane southwest of Clayton as 400 feet and the distance to the Texas spit as 46 miles, we find the gradient to be 3 feet per mile in direction 6 degrees east of north. This suggests that the tilting is steeper toward the north, which is confirmed by an examination of the planes. The stretch from Texas to near Henderson gives 2.5 feet per mile. The stretch from the latter point to the "hogback" hill gives $400 - 315 \div 25.5 = 3.3$ feet per mile.

It is important to compare these gradients with those of corresponding sections of the Iroquois shoreline, which lies nearly parallel and only 5 to 9 miles distant on the east. The section from Richland to Adams compares well in direction and position with the Gilbert Gulf beach from Texas to near Henderson, and the gradient is $640 - 566 \div 17 = 4.4$ feet. It appears that this is nearly twice the tilt of the marine plane. From Adams to Farrs (3 miles east of Watertown), but in a direction more northeasterly, the gradient is $740 - 640 \div 14.5 = 6.9$ feet per mile. This also is about twice that of the marine plane north of Henderson. The entire distance between Richland Junction and Farrs gives, $740 - 566 \div 30$ miles $= 5.8$ feet per mile, which is almost double the grade of the marine plane from Texas to Clayton. Making allowance for uncertainty in the relation of the several datum points to the water planes and for the short distances involved, the harmony in the quantitative relations of the two shorelines is striking. It appears that the deformation of the Iroquois shore is just about twice that of the marine shore. In other words, one-half of the post-Iroquois deformation occurred in the time between the formation of the two beaches, and the other half since the upper marine beaches were deserted. This seems disproportionate, as the fall from Iroquois to Gilbert gulf was only a downdraining of the lake waters through perhaps 230 feet of vertical distance, while the uplift of the land at Clayton has been an exceedingly slow movement through 400 feet. We conclude either that the draining down of the sub-Iroquois waters covered a very long time,

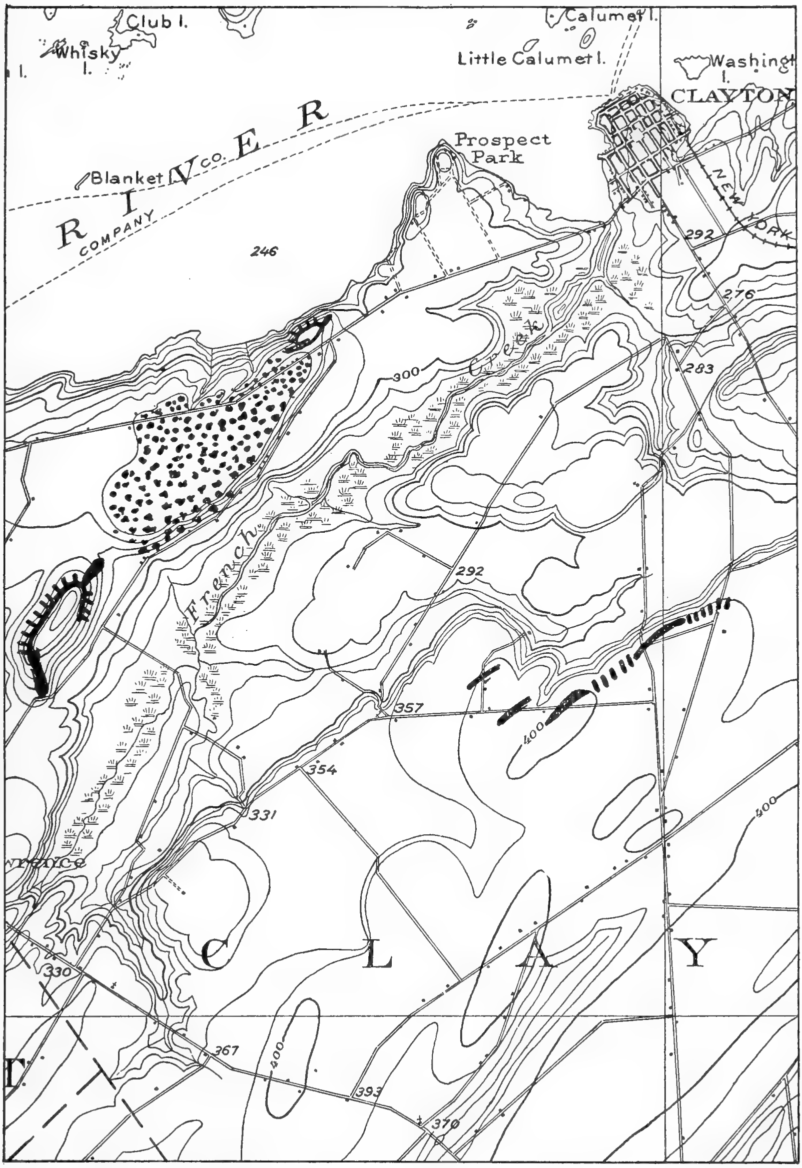


FIGURE 3.—*Gilbert Gulf Shore Features.*

Cliffs, bars, spits, and sand-plain near Clayton. Part of the Clayton topographic sheet slightly reduced.

yet forming no beaches, or that the land tilting was much more rapid during that time than during the later time.

Professor Woodworth concludes that the highest marine level is shown at Covey Hill, on the northern boundary of the state, at 450 feet altitude. This is quite definite, as the higher slopes show only the earlier work of streams carrying the sub-Iroquois waters. In 1882 a whale skeleton was found in a gravel pit at Welchs siding, north of Smiths Falls, in Ontario, and about 30 miles northwest of Ogdensburg. The altitude of the gravels has been given as 440 feet,* and Taylor has told the writer that he estimated the possible upper limit of marine work as about 460 feet. The latter point is only a few miles south of the parallel of Covey Hill, and the altitudes indicate, what has already been inferred from Iroquois and other lake levels in New York, that the isobasal lines in this region trend north of east and south of west.

Welchs siding is 48 miles from the "hogback" hill and in direct continuation of the line from the Texas spit. The uplift between the "hogback" and Welchs, according to the above data, is 1.25 feet per mile. Making all possible allowance for the uncertainty in the figures for the water levels, it seems certain that the rate of uplift diminishes north of Clayton. The deformation of the eastern Ontario region seems to be an irregular warping, with the steepest slopes east of the present lake.

The paper was discussed by H. M. Ami, W. M. Davis, O. C. Lane, J. F. Kemp, and the author.

DISCOVERY OF THE SCHOHARIE FAUNA IN MICHIGAN

BY A. W. GRABAU

[*Abstract*]

During the past season's field work a typical Schoharie fauna was discovered in northern lower Michigan. The locality is at Mill creek, 4 miles east of Mackinac city. The outcrops on the stream are more or less continuous from a short distance south of the mouth of the stream to the top of the terrace along the base of which runs the highway. The lower beds are magnesian calcilutytes, followed by calcarenytes in which the fauna occurs. Two analyses of the rock from different points show:

1. $CaCO_3$	56.12	$MgCO_3$	41.65
2. $CaCO_3$	69.16	$MgCO_3$	27.94

Some of the lowest beds exposed run, however, as high as 94.69 per cent $CaCO_3$ and 2.93 per cent $MgCO_3$.

The outcrops containing the Schoharie fauna are all near the Michigan Central railroad crossing. The fossils, while not well preserved, on the whole are nevertheless characteristic.

The following ten species were obtained:

Trochoceras clio; range, Schoharie.

Atrypa impressa; range, Schoharie.

* A. P. Coleman: Marine and fresh-water beaches in Ontario. Bull. Geol. Soc. Am., vol. 12, p. 133.

Meristella nasuta; range, Schoharie to Onondaga or Hamilton.

Stropheodonta demissa; range, Schoharie to Hamilton.

Pentamerella arata; range, Schoharie to Onondaga.

Rhipidomella alsa; range, Schoharie.

Stenochisma cf. *carolina;* range, Onondaga of northern Ohio and falls of Ohio.

Phacops cristata, Schoharie to Onondaga.

Prœtus latimarginatus, Schoharie.

Dalmanites cf. *anchiops,* Schoharie to Onondaga.

No typical Onondaga species occurs in the fauna, but all are typical Schoharie, though a number range up into the Hamilton. There can, then, be no doubt that this is a typical Schoharie fauna, and that the beds containing it are of Schoharie age, rather than Onondaga, as generally held. These beds are overlain by purer calcarenytes of Onondaga age, ranging 96 per cent or over in $CaCO_3$. The higher beds are brecciated, forming a typical calcirudyte like that of Mackinac island. It is believed that the beds with the Schoharie fauna are the lowest of the series, and that the Monroe (Upper Siluric) beds underlie them. Since the beds of Mackinac island contain an Onondaga fauna, it is evident they can not be lower than those of Mill creek, but the equivalent of the higher (brecciated) beds of that locality. Hence there is a decided flattening of the dip, so that beds at 150 feet above the water level at Mackinac island appear on the main coast at the level of the lake. Instead, then, of a dip of about 30 feet to the mile, or of 40 feet as it is farther east, the dip here is only 15 feet to the mile or even less.

The matter of the paper will be published in the geological reports of the state of Michigan.

The remaining papers of the program were presented by title, as follows:

LITHOLOGICAL CHARACTER OF THE VIRGINIA GRANITES

BY THOMAS LEONARD WATSON

The paper is printed as pages 523-540 of this volume.

RELATION OF CELESTITE-BEARING ROCKS TO OCCURRENCES OF SULPHUR AND SULPHURETTED WATERS

BY EDWARD H. KRAUS

NEW SPECIES OF SODA-ALUMINA PYROXENE

BY S. WEIDMAN

ORIGIN OF LEACHED PHOSPHATES

BY C. H. HITCHCOCK

GRADED SURFACES

BY F. P. GULLIVER

CALABRIAN EARTHQUAKE OF SEPTEMBER 8, 1905

BY WILLIAM HERBERT HOBBS

[*Abstract*]

The Calabrian earthquake of September 8, 1905, was the most severe in that seismically classical region for more than a century, and its relations to the lineaments of the Calabrian peninsula are most interesting. The losses to life and property as reported to the writer by the Ministry of the Interior of the Italian Government* were as given in the following table:

Province.	Number of persons killed	Number wounded.	Property losses in Italian lire.
Cosenza	47	222	20,500,000
Catanzaro	480	1,598	20,500,000
Reggio Calabria	2	57	7,000,000
	529	1,877	48,000,000

Early in the following October all sections of the afflicted region were visited by the writer, and attention was devoted especially to the distribution of damage to determine the relation of the destructive force of the shocks to the topographic features and the geologic structure.

In Monteleone, a city of 13,000 inhabitants, located near the center of the affected region, the buildings along a single street were leveled by the shocks, whereas elsewhere in the city all houses remained standing.* The direction of this street extended intersected ruined villages in the *paese*. With the clue afforded by this interesting observation, application for further information was made at the military headquarters of the forces engaged in succoring the afflicted people. General Ferrario exhibited to the writer a large scale topographic map of the region, upon which had been plotted the data of detailed reports from subordinate commands, and which revealed by spots of two different colors, first, the communes which had sustained damage, and, second, those which had been largely wrecked and in which there was the direst distress. The dense population of Calabria made this map one of very great interest, for a network of destructive zones was apparent and had been recognized by the staff officers. The straight elements of this network were marked topographic features and in many instances well-known fault-lines.

The field work completed, a study of the unusually complete earthquake records of Calabria—records extending over three centuries—was undertaken at Rome and yielded the following general conclusions:

First. The same communes have been either repeatedly damaged by earthquakes or have remained unscathed. To each a figure may be assigned to indicate in a roughly made scale its relative seismicity.

Second. The seismically prominent communes are arranged in lines—*seismotectonic lines*—corresponding in position to those revealed by the damage

* Through the kind offices of the American Embassador at Rome.

† It was afterward ascertained that the houses upon this street had been the first to be leveled by the terrible earthquake of 1783.

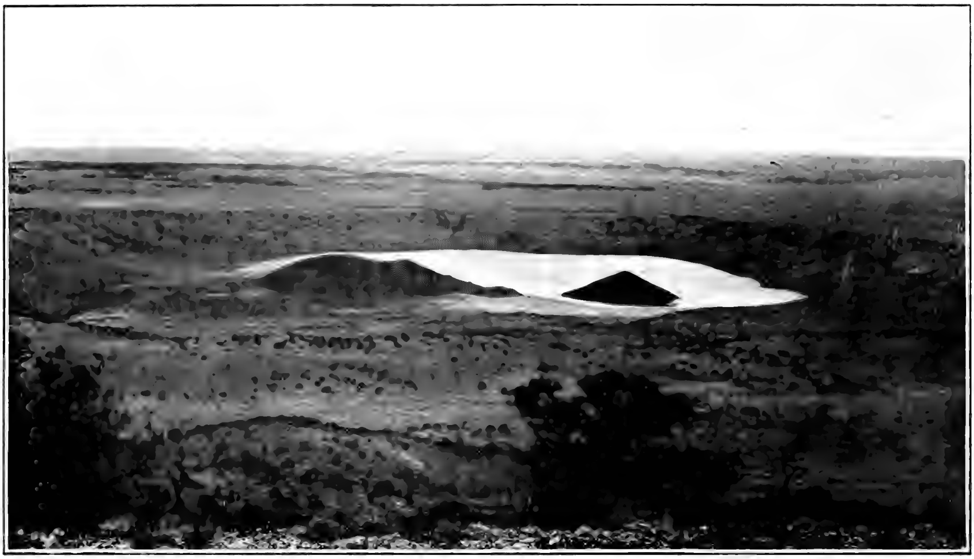


FIGURE 1.—INTERIOR VIEW OF CRATER

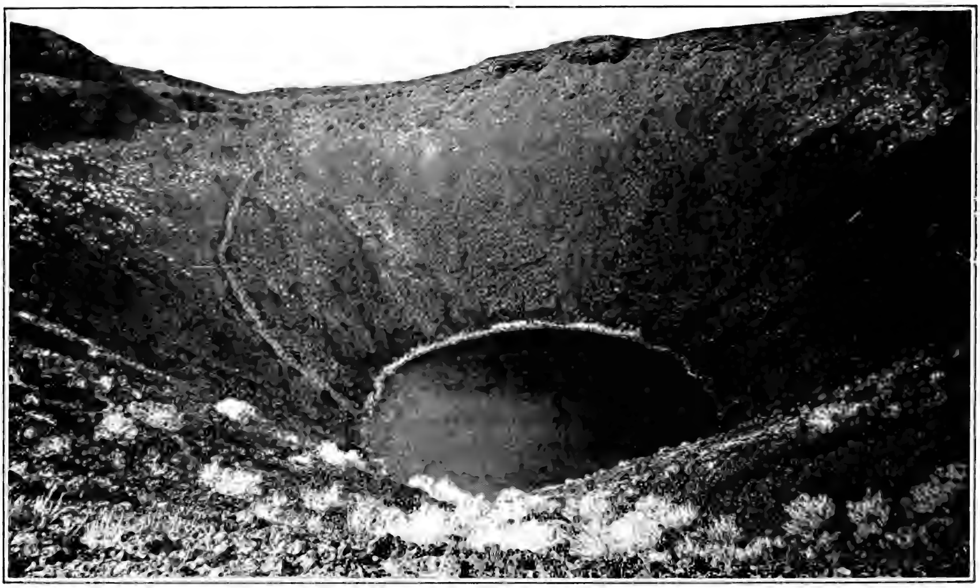


FIGURE 2.—LAKE IN BOTTOM OF CINDER CONE SHOWN IN FIGURE 1

CRATER SALT-LAKE

map of the earthquake of 1905, and these lines are prominent lineaments and in many cases known faults.

Third. The communes of highest seismicity lie at the intersections of seismotectonic lines.

Fourth. Within an area common to the destructive territory of three catastrophic earthquakes (1659, 1783, and 1905) whose "centrums" were widely separated, the distribution of damage was essentially the same—the included communes maintained the same relative position as regards the damage sustained.

From these facts it appears that earthquakes have no centrum as this term is ordinarily understood, but in so far as so-called epicenters are positions of greatest intensity of shocks, they are numerous and habitual and correspond to the intersection of fissure planes projected upon the surface. It also appears that shocks of earthquakes below X in the Rossi-Forel Scale are impotent to wreck well constructed buildings at distances of a mile or more from the fissure planes.

When the investigation was about completed there appeared the epochmaking work of the Count de Montessus de Ballore* upon the distribution of seismicity and its relation to topography and geology—"seismic geography." Upon a large scale adapted to the methods used, Major de Montessus has located the habitual epicenters for all earthquake provinces of the globe. Applying the methods discovered in Calabria to the maps of de Montessus, it is found that almost throughout the habitual epicenters are the intersections of important lineaments.

A special study has been made of the eastern United States and Canada on the basis of data supplied by de Montessus, and it is found that the habitual epicenters of this large region are the intersections of the grand lineaments as they have already been plotted* with others brought to light by a consideration of the steep walls of the continental shelf. The full reports are to appear as heft 2 of volume viii of the Beiträge zur Geophysik, the journal of the International Seismological Association.

GUADIX FORMATION OF GRANADA, SPAIN

BY WILLIAM H. HOBBS

This paper is printed as pages 285-294 of this volume.

VOLCANIC CRATERS IN THE SOUTHWEST

BY CHARLES R. KEYES

Several years ago Mr G. K. Gilbert aroused considerable interest among scientists by the announcement that he had visited in Arizona a large crater, depressed below the level of the plains, about which large numbers of meteoric masses had been found. The main hypothesis considered regarding the origin of the depression was that of a large meteorite striking the earth at this point. The phenomenon is thus described:*

* Les tremblements de terre, Paris, 1906.

* Lineaments of the Atlantic border region. Bull. Geol. Soc. Am., vol. 15, 1904, pp. 483-506, pls. 45-47.

* Presidential address before Geological Society of Washington, 1896.

"In northeastern Arizona there is an arid plain beneath whose scanty soil are level beds of limestone. At one point the plain is interrupted by a bowl-shaped or saucer-shaped hollow, a few thousand feet broad and a few hundred feet deep; and about this hollow is an approximately circular rim, rising 100 or 200 feet above the surface of the plain. In other words, there is a crater; but the crater differs from the ordinary volcanic structure of that name in that it contains no volcanic rock. The circling sides of the bowl show limestone and sandstone, and the rim is wholly composed of these materials. On the slopes of this crater and on the plain round about many pieces of iron have been found, not iron ore, but the metal itself, and this substance is foreign to the limestone of the plain and to all other formations of the region. The features of the locality thus include three things of unusual character and requiring explanation: First, the crater composed of non-volcanic rock; second, the scattered iron masses; third, the association of crater and iron. To account for these phenomena a number of theories have been suggested.

"More precisely, the locality is a few miles south of the station of Canyon Diablo and directly west of Winslow, on the Atlantic and Pacific division of the Santa Fe railroad. The locality is known as Coon butte."

It is unnecessary at this time to go into further detail of Mr Gilbert's interesting discussion. Suffice it to say, while evidences of extensive volcanic action are abundant in the region, there are no lava flows or volcanic materials in the immediate vicinity of Coon butte. The fact of the entire absence of volcanic materials was the chief reason that the falling star hypothesis appeared so attractive.

There are in northeastern Arizona and New Mexico myriads of volcanic cones. Many of these are symmetrical cinder cones; some are low lava cones; some are cinder cones with breached craters from which basalt flows extend for several miles; some are the centers from which the country has been flooded with lava for many miles all around. A number of these volcanic vents display evidences of dry explosive action. To one of these special attention is called, for the reason that it is similar to Coon butte in every respect, as described by Mr Gilbert, except that from the bottom of the crater rise two small cinder cones. This locality is known as Crater salt-lake and is in the western part of Socorro county, in New Mexico (plate 80, figure 1). The bottom of the crater is a salt-lake, whence the name. In this respect it also differs from the Coon Butte crater. A geological cross-section of the Crater salt-lake is represented in the diagram below (figure 1).

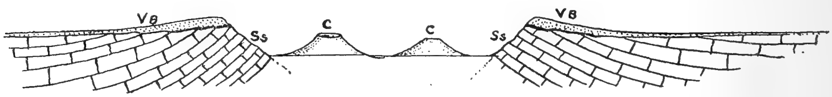
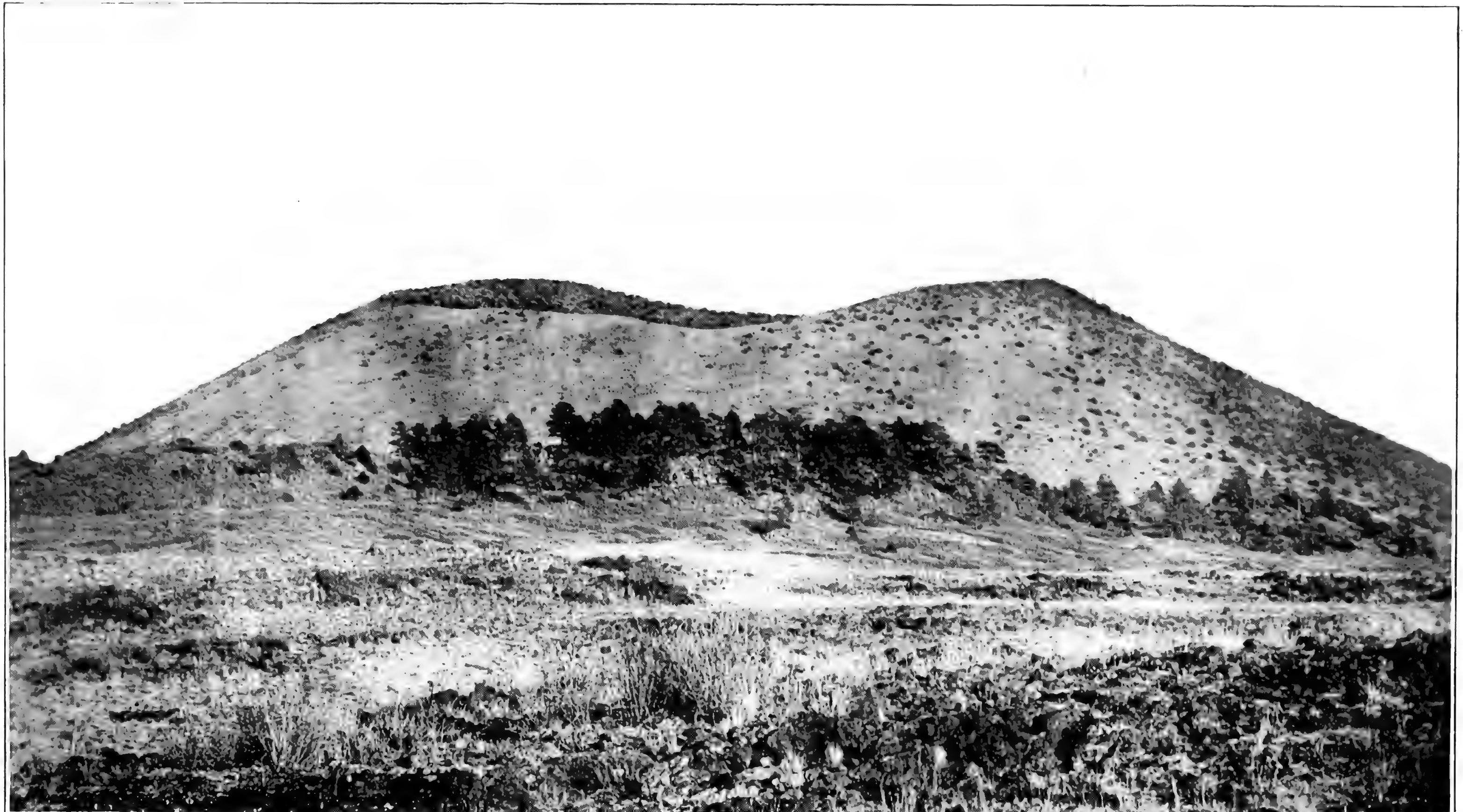


FIGURE 1.—*Geological Cross-section of Crater Salt-lake.*

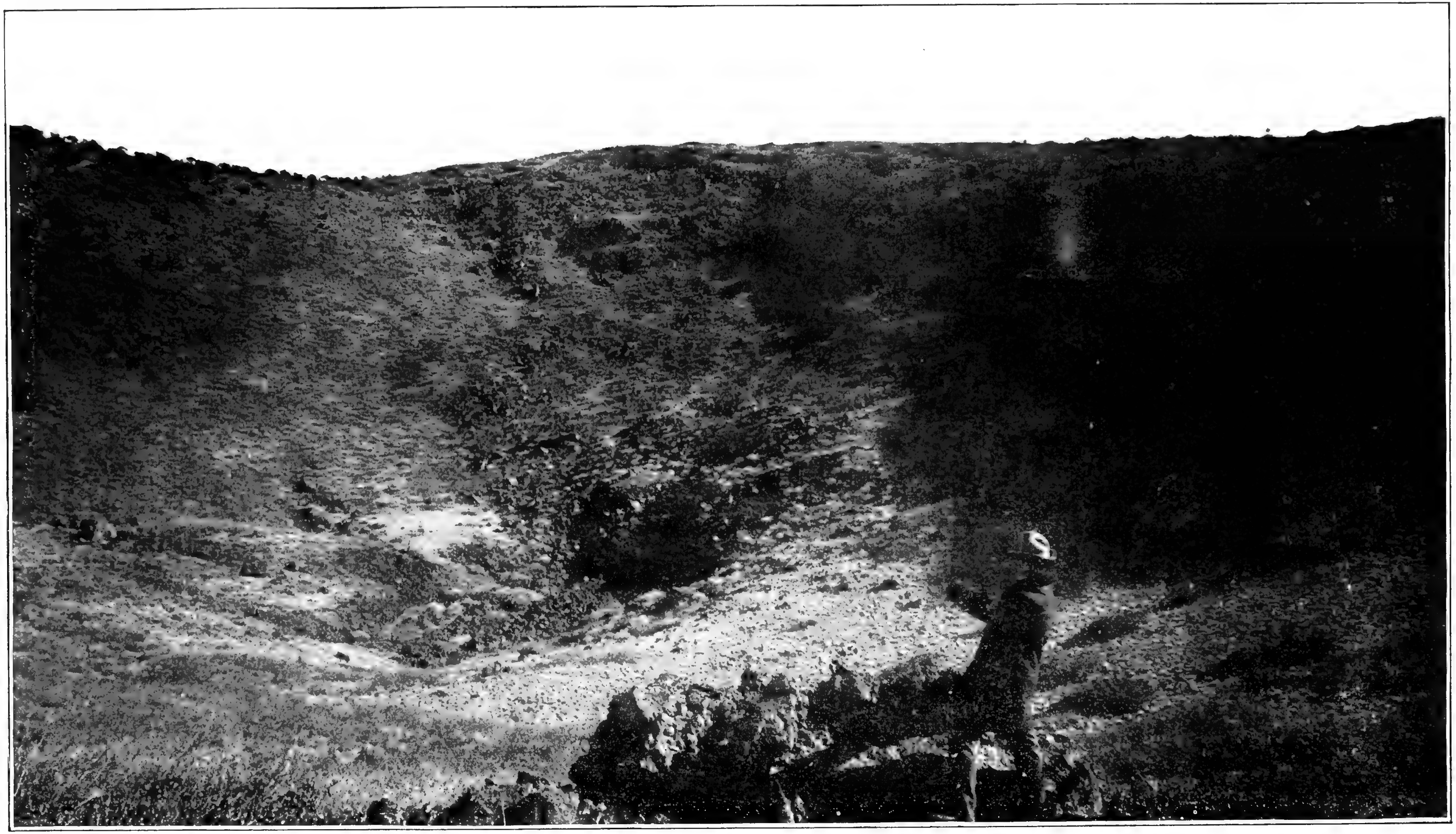
Within the crater of the small cinder cone which rises out of the bottom of the lake there was formerly a diminutive lake, which is shown in the accompanying view (plate 80, figure 2).

The important feature, however, of Crater salt-lake is that it displays a stage in its formation that is wholly wanting in the case of Coon butte. Conclusive evidence is here furnished that the craters in plains are the result of



MOUNT CAPULIN, NEW MEXICO

A huge ash cone of very recent formation



INTERIOR OF CRATER OF MOUNT CAPULIN

CENTRAL PLUG OF MOUNT CAPULIN

LAVA FIELDS AND VOLCANIC CONES, NEW MEXICO

View from top of mount Capulin. Nearest cone in center of field is 15 miles distant

the explosive action of local vulcanism. If they were located anywhere but in an arid region, they would always be filled with water. Now they are either dry or are salt lakes in the last stage of desiccation.

Crater salt-lake lies between 200 and 300 feet below the rim. It is excavated from sandstones of Cretaceous age, while Coon butte crater is hollowed out of Carboniferous limestones. Crater salt-lake is bordered all around by a broad zone of unconsolidated pyroclastic material. From one side also extends a narrow basalt flow.

In the region are other stages of volcano building. There are low volcanic cones in which the amount of fine dry material blown out has nearly covered up all evidences of disturbances in the indurated strata beneath. Some craters of similar cones have also lava flows miles in length. The single basaltic stream from Maxwell cone, north of Las Vegas, extends a distance of 30 miles. From a small crater in the bolson plain lying between the Jicarilla and Oscura mountains, in central New Mexico, a lava stream 2 to 4 miles wide follows the central depression of the plain a distance of over 50 miles.

The most majestic of these dry eruptions is mount Capulin, in northeastern New Mexico (see plate 81). This is a lofty cinder cone 2,500 feet high, with a crater half a mile across and 500 feet deep. Plate 82 is a view taken from one side of the rim, and plate 83 a near view of the central plug of lava at the bottom of the crater. A view of other cones in the vicinity as seen from the top of the mountain and of the lava fields is shown in plate 84.

Mount Capulin is far more imposing than Vesuvius. In the fine, light, scoriaceous material of which it is mainly composed one sinks knee-deep in climbing its steep sides. On the southwest side the crater wall is breached and the heavy lava flow extends for many miles around. In the bottom of the crater the old plug of solid lava is well displayed.

Mount Capulin is as fresh in appearance today as is Vesuvius. There is a local tradition that the mountain was in action as late as 1812. If this is so, it is the latest volcanic eruption in the United States. The twin-cratered Sierra Grande, 15 miles to the east of mount Capulin and rising much higher (11,000 feet above tide), is reported to still show signs of dying activity, and the heat in the craters is sufficient to melt the falling snow.

From Coon butte, through Crater salt-lake and a host of nameless craters, to mount Capulin are represented all the stages of dry explosive action of volcanic forces. Coon butte stands at one extreme, mount Capulin at the other. In Coon butte we find the first stage of volcano construction—a stage rarely met with. Crater salt-lake represents a more advanced stage and is equally unique.

The two following papers, which were presented under the title Hawaiian Notes, are printed as pages 469-496 of this volume.

GEOLOGY OF DIAMOND HEAD, OAHU

BY C. H. HITCHCOCK

MOHOKEA CALDERA

BY C. H. HITCHCOCK

ALGONKIAN FORMATIONS OF NORTHWESTERN MONTANA

BY CHARLES D. WALCOTT

The paper is printed as pages 1-28 of this volume.

PALEOGEOGRAPHY OF SAINT PETER TIME

BY CHARLES P. BERKEY

The paper is printed as pages 229-250 of this volume.

CARBONIFEROUS OF THE APPALACHIAN BASIN

BY JOHN J. STEVENSON

The paper is printed as pages 65-228 of this volume.

OVERLAP RELATIONS ALONG THE ROCKY MOUNTAIN FRONT RANGE IN WYOMING AND COLORADO

BY N. H. DARTON

RED BEDS IN THE LARAMIE MOUNTAIN REGION

BY N. H. DARTON

[*Abstract*]

During the past season many additional observations were made on the Red beds at various localities in central Wyoming, especially in the vicinity of the Laramie and Bighorn mountains. One of the most significant features was the discovery of a fossiliferous limestone 150 feet below the top of the Red beds, containing a Permo-Carboniferous fauna. The locality was on the Bighorn river 3 miles north of Thermopolis, Wyoming, on the west slope of the Bighorn uplift. The Red beds in this region are nearly 1,000 feet thick and lie upon a well defined series of Upper Carboniferous limestones and sandstones. In the basal portion of the Red beds in this vicinity and elsewhere Permo-Carboniferous fossils have been obtained in previous seasons. The occurrence of this same fauna at the higher horizon leaves only 150 feet of red shales which may represent the Triassic. The next succeeding formation is the marine Jurassic, which appears to lie unconformably on the Red beds.

An examination was made of the locality from which Professor Wilbur Knight obtained Carboniferous fossils in the Red beds near Laramie several years ago. His collections were made in vicinity of Red mountain, near the southern margin of the Laramie basin. It was found that on both sides of Laramie mountain the Upper Carboniferous sandstones and limestones in their southern extension grade into and thereby give place to a thick deposit of Red beds. These, along the Rocky Mountain front, become the Lower Wyoming division of Eldridge and the Fountain formation of Gilbert and Cross. The Red beds which overlie the Upper Carboniferous limestones northward continue unchanged into the region of Lower Wyoming-Fountain red-beds as a distinct division, which was recognized by Eldridge as the Upper Wyoming division. The upper division has been designated the Chugwater formation.

This determination, which I made several years ago and announced to the Society, was verified in the region south of Laramie, where we found the lower division represented by a thick mass of red grits with occasional beds of limestone. It was in the upper portion of this series that Professor Knight obtained an extensive collection of Upper Carboniferous fossils, which verified the idea that the lower Red beds represent the southern extension of Upper Carboniferous limestones and sandstones of the region north. The overlying Red beds, which I recognized as the Chugwater formation, are several hundred feet thick, and I learned that in these Professor Williston has obtained, from near Red Mountain, the remains of vertebrates which are regarded as Triassic in age. As from the molluscan remains it would appear that the greater part of the Chugwater formation in the region north is of Permo-Carboniferous age, there is here an apparent contradiction of the evidence. So the matter stands at present, but during the coming season a special investigation will be made to obtain additional paleontologic facts.

TERTIARY TERRANES IN NEW MEXICO

BY CHARLES R. KEYES

[*Abstract*]

In the general survey which has been taken recently of the Tertiary formations of the region much new information has been obtained. The work of a generation ago has been adjusted to the new scheme. Some of the Tertiary formations are typical fluviatile deposits; others were deposited in water. Eocene, Miocene, and Pliocene epochs are represented by depositions. The general section is as follows:

Pliocene	Llano Estacado formation	300 feet.
Miocene	Santa Fe sands	800 "
	Chama clays	300 "
Eocene	Chaco marls	1,000 "
	Canyon Largo sandstones	700 "
	Torreon formation	300 "
	Puerco clays	500 "

The Tertiary deposits of New Mexico are much wider spread than has been supposed. As the period was marked by extensive volcanic action, the lava flows and intrusions have important relationships to many of the formations. The recent ascribing of a fluviatile origin to most of the Tertiary formations of the region is believed to be erroneous, and is due largely to a confusion of Quatenary deposits with the more recent Tertiary beds. The discriminating criteria of fluviatile formations are discussed in this paper.

QUATERNARY HISTORY OF THE UPPER MISSISSIPPI VALLEY

BY WARREN UPHAM

[*Abstract*]

Evidences of preglacial high uplift of this region, as also of all the glaciated area of the continent, are noted; and this altitude, continuing nearly to the end

of the Glacial period, is regarded as the chief cause of its vast accumulation of snow and ice. The several stages of advance or growth of the ice-sheet, interrupted by repeated recessions and readvances, are reviewed, as made known by their series of till deposits, moraines, and stratified or modified drift. Among the peculiar features of the upper Mississippi region are the large driftless area lying mostly in Wisconsin, inclosed on all sides by the glacial drift; the loess, extensively developed west and south of that area; and the falls of Saint Anthony, which, with the gorge extending 8 miles downstream to Fort Snelling, give an estimate of the duration of the post-Glacial period as about 7,000 years. All the Mississippi valley above the mouth of the Ohio is included in this study, but especial attention is directed to its higher part, in Minnesota, from lake Itasca to lage Pepin.

FISH REMAINS IN ORDOVICIAN IN BIGHORN MOUNTAINS, WYOMING, WITH A RESUME OF ORDOVICIAN GEOLOGY OF THE NORTHWEST

BY N. H. DARTON

The paper is published as pages 541-566 of this volume.

DISTRIBUTION OF DRUMLINS AND ITS BEARING ON THEIR ORIGIN

BY FRANK B. TAYLOR

[*Abstract*]

This paper presents a discussion of certain aspects of drumlins and drumlin areas. They are considered with reference to their distribution in the regions of Pleistocene glaciation; in their relation to the larger elements of topography; to the marginal portions of the ice-sheet, and to the successive recessional halts of the retreating ice-front.

Drumlin areas occur typically in association with broad basins or lowlands, such as our Great Lake basins and the lowlands of Scotland, Ireland, and Scandinavia. Certain occurrences of drumlins which are apparent exceptions to this rule are briefly considered. Drumlins are usually classed as forms made under deep ice. The writer's studies indicate that while this is true, there are certain facts which qualify such a statement. The relation of drumlins to the ice-margin, as shown by studies in Ontario and western Massachusetts, seems to support the view that drumlins are submarginal forms, made neither at the edge of the ice nor many scores of miles back under it, but in a submarginal belt varying roughly from five to 20 miles in width and beginning 1 to 5 miles back from the edge of the ice. The elongation of drumlins, or rather the ratio of the horizontal axes, is principally dependent upon the velocity of ice movement during their formation. Drumlins are conspicuous by their absence in certain regions which seem in many ways favorable for their formation, namely, in Ohio, Indiana, Illinois, southern Michigan, and parts of Ontario. No reason has been given for this peculiarity. Some tentative suggestions are made bearing on this point.

GEOLOGICAL MAP OF CONNECTICUT, 1905

BY H. E. GREGORY

[*Abstract*]

A complete and remarkably accurate geological map of Connecticut by James G. Percival was issued by the state in 1842. Since that date maps have appeared in reports and text books—for example, Dana revised 1897, Le Conte revised 1903, Brigham 1903, and McGee 1893—which represent the crystalline rocks of Connecticut as largely granite and Archean in age. A preliminary geological map of Connecticut by Herbert E. Gregory and H. H. Robinson is now ready for publication. The map shows practically no granite or other unmetamorphosed igneous rock except basalt and diabase. No rock of undoubted Archean age has been shown to occur within the borders of the state.

LOESS-CYCLE IN TURKESTAN

BY R. PUMPELLY

The scientific program was declared closed.

RESOLUTION OF THANKS

The following resolution was offered by Professor S. Calvin and unanimously adopted:

Resolved, That the Ottawa meeting of the Geological Society of America will long be remembered as one of great profit and pleasure to all the Fellows of the Society who had the good fortune to be present. For the success of the meeting we recognize our indebtedness to local organizations and individuals more in number than can here be named. We would especially mention the Logan Club and the members generally of the staff of the Geological Survey of the Dominion of Canada, whose thoughtful foresight and painstaking arrangements for our accommodation and comfort left nothing to be desired; Principal J. F. White, to whose generosity we are indebted for the use of commodious rooms in the Normal School building; their Excellencies the Governor General and the Countess Grey, and many citizens of Ottawa, who placed us under lasting obligations for gracious courtesies and kindly expressions of sympathy with the work for which our Society stands. To each and all who have thus contributed to the success of our meeting we express sincere appreciation and extend grateful thanks.

President Pumpelly made brief remarks and declared the meeting closed.

No formal session of the Society was held in the evening, but the customary annual dinner was given, at the Russell House, at which His Excellency the Governor General was present with other guests.

Following the dinner a reception was given by the Logan Club in the Russell House parlors.

Register of the Ottawa Meeting, 1905

The following Fellows were in attendance at the meeting:

F. D. Adams.
José G. Aguilera.
H. M. Ami.
Robert Bell.
R. W. Brock.
A. H. Brooks.
Samuel Calvin.
J. M. Clarke.
A. P. Coleman.
W. M. Davis.
S. F. Emmons.
H. L. Fairchild.
C. N. Gould.
C. W. Hayes.
J. F. Kemp.
H. B. Kümmel.
A. C. Lane.
C. K. Leith.
R. G. McConnell.
William McInnes.
G. P. Merrill.
W. G. Miller.
G. H. Perkins.
Raphael Pumpelly.
Heinrich Ries.
I. C. Russell.
W. H. Sherzer.
G. O. Smith.
R. S. Tarr.
J. B. Tyrrell.
T. L. Walker.
David White.
A. W. G. Wilson.
F. E. Wright.

Fellows-elect

R. A. Daly.
J. D. Irving.
A. P. Low.
F. A. Wilder.
G. A. Young.

Total attendance, 39.

Session of the Cordilleran Section, Friday, December 29, 1905

The seventh annual meeting of the Cordilleran Section of the Society was called to order at 10.30 a m, December 29, 1905, in South Hall, Berkeley.

The Chairman of the Section, President W. G. Tight, presided.

The minutes of the last meeting were read and approved.

The following officers were elected for the ensuing year: J. C. Branner, Chairman; George D. Louderback, Secretary, and W. C. Mendenhall, Councillor.

On the invitation of President Tight, it was resolved to hold the next meeting but one at Albuquerque, New Mexico, if arrangements could be made to that end by the Executive Committee.

The following papers were then read and discussed:

AFFINITIES AND STAGE OF EVOLUTION OF THE JOHN DAY CARNIVORA

BY JOHN C. MERRIAM

TEHACHAPI VALLEY

BY ANDREW C. LAWSON

[*Abstract*]

Tehachapi valley lies on the summit of the southern Sierra Nevada and drains to Mohave desert on the one side and to the San Joaquin valley on the other, in both cases through steep rocky gorges. The valley is about 12 miles long and at its widest part 5 miles or more wide. Its floor is a nearly flat surface of alluviation and the divide for the drainage is in the middle of this flat floor. The paper is a description of this valley and a discussion of its origin as a geomorphic feature. Other similar features in the same region are also discussed in the paper.

The paper was illustrated by lantern slides. It was published as Bulletin of the Department of Geology, University of California, volume 4, no. 19.

MIDDLE KERN RIVER

BY ANDREW C. LAWSON

Published as Bulletin of the Department of Geology, University of California, volume 4, no. 16.

The Section then adjourned for luncheon.

At 2 p m the session was resumed and the following papers were read:

IGNEOUS ROCKS OF THE NORTHWESTERN BLACK HILLS

BY W. S. TANGIER SMITH

[*Abstract*]

The igneous rocks of this region belong to two widely separated periods of time, the first pre-Cambrian, the second probably post-Cretaceous or Eocene. The Eocene (?) igneous rocks form an interesting group of closely related types, all of which have probably been derived by differentiation from a common, somewhat soda-rich magma. They constitute the laccolithic intrusions characteristic of this part of the Black hills, and appear also as associated minor masses.

Brief petrographic descriptions of the more important of these rocks, as well as their general relationships, are given in the paper.

CALCITE FROM TERLINGUA, TEXAS

BY A. S. EAKLE

Published in Bulletin of the Department of Geology, University of California, volume 5, no. 6.

ALTERATION OF SERPENTINE

BY A. KNOPF*

Published as Bulletin of the Department of Geology, University of California, volume 4, no. 18.

PLEISTOCENE PHENOMENA IN THE MISSISSIPPI BASIN; A WORKING HYPOTHESIS

BY W. G. TIGHT

[*Abstract*]

The present hypothesis proposes that prior to the earliest ice invasion of the Pleistocene the drainage of the upper Mississippi basin was to the northward. The early ice movements in occupying this basin were forced to advance against the general slope of the basin, and hence the ice-front advanced upon a rising plane. This produced frontal impounding of the drainage waters, with the development of extensive frontal lakes and accompanying sluggish action of the ice-front, poorly developed moraines, extra morainic drift, and sluggish movement of the gravel trains from the margin of the ice. A new outlet to the basin was developed along the line of the middle Mississippi section, which became well established as the upper Mississippi drainage developed, with the early recession of the ice. Later ice invasions into the basin followed the established gradients, developed into extensive lobate forms, produced only local and minor frontal lake phenomena, almost no extra-morainic drift, show strong morainic development and vigorous action of streams discharging from the ice-front.

The Section then adjourned till next morning.

Session of the Cordilleran Section, Saturday, December 30

The Section was called to order at 10 a m, President W. G. Tight in the chair.

The following papers were read and discussed:

CRECENTIC GOUGES ON GLACIATED SURFACES

BY G. K. GILBERT

Printed as pages 303-316 of this volume.

MOULIN WORK UNDER GLACIERS

BY G. K. GILBERT

Printed as pages 317-320 of this volume.

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* Introduced by Andrew C. Lawson.

EXPLORATION OF THE FAMWEL CAVE

BY E. L. FURLONG*

Published in the American Journal of Science, xxii, 235-247 (1906).

EXCEPTIONAL NATURE AND GENESIS OF THE MISSISSIPPI DELTA

BY E. W. HILGARD

[*Abstract*]

This paper discusses the wholly exceptional materials and form of the lower delta of the Mississippi river, as observed by the writer in 1867 and 1869, and described and discussed in the American Journal of Science in 1871. Following out the suggestions of Lyell and the disputed statement of Humphreys and Abbott that the alluvial deposits of the great river are only of slight depth, the writer investigated the extreme mouths of the passes, the "neck," and the similar minor, birdfoot-like arms projecting beyond. It became apparent that the silty river deposit on these narrow dikes or banks is only superficial, and that their resistance to erosion during overflows is due to their being mainly composed of tough, inerodable "mudlump clay." That these mudlumps, observed and described by Lyell, are upheavals of the river bottom, and are formed of such clay as is deposited *outside* of the bar, where the turbid water of the river meets and is clarified by the saline sea water; also, that the mudlump upheavals occur in the *main* outlets or passes of the river, as a direct result of their being the main outlets. No mudlumps then existed in the South pass, but now that it has been artificially made the main channel, *mudlump* upheaval has taken and is taking place. Mudlump formation is thus the normal mode of progression of the delta of the main Mississippi.

No such phenomena are known to occur in any other river of the world; hence no other river has such birdfoot mouths. The Mississippi delta should not, therefore, be longer presented as the type of a normal delta, as is done by Russell in his "Rivers of North America."

The Section then adjourned for luncheon.

At 2 p m the session was resumed and the following papers were read:

INTERREGIONAL ZONES IN THE TRIASSIC OF WESTERN NORTH AMERICA

BY J. P. SMITH *

A NEW AMPHIBOLE

BY W. O. CALRK†

NOTES ON PALEOZOIC CHERTS FROM MISSOURI

BY F. B. LANEY‡

* Introduced by John C. Merriam.
† Introduced by A. S. Eakle.
‡ Introduced by Andrew C. Lawson.

GEOLOGICAL RECONNAISSANCE OF THE COAST OF THE OLYMPIC PENINSULA, WASHINGTON

BY RALPH ARNOLD

Printed as pages 451-468 of this volume.

GRAVITATIONAL ASSEMBLAGE IN GRANITE

BY G. K. GILBERT

Printed as pages 321-328 of this volume.

The Section passed a resolution of thanks to the University of California for having placed the rooms of South Hall at the disposal of the Society for the purposes of the meeting.

The Section then adjourned.

ANDREW C. LAWSON,
Secretary.

REGISTER OF THE MEETING OF THE CORDILLERAN SECTION

The following Fellows were in attendance at the meeting:

F. M. ANDERSON.
R. ARNOLD.
A. S. EAKLE.
G. K. GILBERT.
E. W. HILGARD.
A. C. LAWSON.
G. D. LOUDERBACK.
R. H. LOUGHRIDGE.
W. C. MENDENHALL.
J. C. MERRIAM.
W. S. TANGIER SMITH.
W. G. TIGHT.

The visitors were:

E. P. CAREY.
E. L. FURLONG.
R. S. HOLWAY.
A. KNOPF.
F. B. LANEY.
D. T. SMITH.
J. P. SMITH.
C. E. WEAVER.
H. O. WOOD.

ACCESSIONS TO LIBRARY FROM JULY, 1905, TO OCTOBER, 1906

BY H. P. CUSHING, *Librarian*

Contents

(*A*) FROM SOCIETIES AND INSTITUTIONS RECEIVING THE BULLETIN AS DONATION ("EXCHANGES")

(*a*) AMERICA

NEW YORK STATE MUSEUM, ALBANY

2660. Bulletin 77.
2851–2852. Museum Report 57, parts 1–2.
2853–2858. Bulletins 78, 80–89, 91, 93–98.

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

2620. Proceedings, vol. 32, nos. 5–12.

MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

2753. Anales, serie 3, tomo iv.
2848. Anales, serie 3, tomo v.

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2181. Report series, vol. ii, no. 5.
2402. Geological series, vol. ii, nos. 7–9.
2715. Geological series, vol. iii, nos. 2–4.
2925. Zoological series, vol. vii, nos. 2–3.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

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2892. Boletin 28–34.

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2829. Boletin, numero 20–21.
2504. Parergones, tomo 1, num. 9–10.

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2649. Bulletin, vol. xxxvii, nos. 7–12.
2859. Bulletin, vol. xxxviii, nos. 1–4.

AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK

2150. Bulletin, vol. xvii, parts 3–4.
2842. Bulletin, vol. xxi.
2843. Memoirs, vol. ix, parts 1–3.

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IMPERIAL UNIVERSITY OF TOKYO, TOKYO

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E. V. D'INVILLIERS

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H. L. FAIRCHILD

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C. H. HITCHCOCK

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E. O. HOVEY

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J. H. PRATT

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C. D. WALCOTT

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ATREUS WANNER

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OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1906

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E. A. Smith, University of Alabama

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H. M. Ami, Ottawa, Canada
J. F. Kemp, New York city

(Term expires 1908)

A. C. Lane, Lansing, Mich.
David White, Washington, D. C.

FELLOWS IN DECEMBER, 1906

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., Mount Weather, Va. August, 1899.

Frank Dawson Adams, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

George I. Adams, Sc. D., Corps of Mining Engineers, Lima, Peru. December, 1902.

José Guadalupe Aguilera, Director del Instituto Geologico de Mexico, City of Mexico, Mexico. August, 1896.

Truman H. Aldrich, M. E., 1739 P St. N. W., Washington, D. C. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Frank M. Anderson, B. A., M. S., 2604 Ætna Street, Berkeley, Cal. In California State Mining Bureau. June, 1902.

Philip Argall, 728 Majestic Building, Denver, Colo.; Mining Engineer. August, 1896.

Ralph Arnold, Ph. D., Washington, D. C.; Geologic Aid U. S. Geological Survey. December, 1904.

George Hall Ashley, M. E., Ph. D., Washington, D. C., U. S. Geological Survey. August, 1895.

Harry Foster Bain, M. S., Champaign, Ill., State Geological Survey. December, 1895.

Rufus Mather Bagg, Jr., Ph. D., West Springfield, Mass.; Mining Geologist. December, 1896.

S. Prentiss Baldwin, 736 Prospect St., Cleveland, Ohio. August, 1895.

Sydney H. Ball, A. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

Erwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

Joseph Barrell, Ph. D., New Haven, Conn.; Asistant Professor of Geology, Yale University. December, 1902.

George H. Barton, B. S., Boston, Mass.; Curator, Boston Society of Natural History. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr, Pa.; Professor of Geology, Bryn Mawr College. August, 1894.

William S. Bayley, Ph. D., Urbana, Ill.; Assistant Professor of Geology, University of Illinois. December, 1888.

*George F. Becker, Ph. D., Washington, D. C., U. S. Geological Survey.

Joshua W. Beede, Ph. D., Bloomington, Ind.; Instructor in Geology, Indiana University. December, 1902.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Acting Director of the Geological and Natural History Survey of Canada. May, 1889.

Charles P. Berkey, Ph. D., New York city; Columbia University. August, 1901.

Samuel Walker Beyer, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Arthur Bibbins, Ph. B., Baltimore, Md.; Instructor in Geology, Woman's College. December, 1903.

Albert S. Bickmore, Ph. D., American Museum of Natural History, New York; Professor in charge of Department of Public Instruction. December, 1889.

Irving P. Bishop, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

John M. Boutwell, M. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

John Adams Bownocker, D. Sc., Columbus, Ohio.; Professor of Inorganic Geology, Ohio State University. December, 1904.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford, Jr., University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

Reginald W. Brock, M. A., Ottawa, Canada, Geologist, Geological and Natural History Survey of Canada; Professor of Geology, School of Mining, Kingston. December, 1904.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1899.

Amos P. Brown, Ph. D., Philadelphia, Pa.; Professor of Mineralogy and Geology, University of Pennsylvania. December, 1905.

Ernest Robertson Buckley, Ph. D., Rolla, Mo.; State Geologist and Director of Bureau of Geology and Mines. June, 1902.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Franklin R. Carpenter, Ph. D., 1420 Josephine St., Denver, Colo.; Mining Engineer. May, 1889.

Ermine C. Case, Ph. D., Milwaukee, Wis.; Instructor in State Normal School. December, 1901.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Tacoma, Wash. August, 1891.

Frederick G. Clapp, S. B., Washington, D. C.; Geologic Aid, U. S. Geological Survey. December, 1905.

*William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Albany, N. Y.; State Paleontologist. December, 1897.

Herdman F. Cleland, Ph. D., Williamstown, Mass.; Professor of Geology, Williams College. December, 1905.

J. Morgan Clements, Ph. D., 15 William St., New York city. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

Arthur P. Coleman, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

George L. Collie, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

Arthur J. Collier, A. M., S. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. June, 1902.

*Theodore B. Comstock, Sc. D., Los Angeles, Cal.; Mining Engineer.

*Francis W. Cragin, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

Alja Robinson Crook, Ph. D., Springfield, Ill.; State Museum of Natural History. December, 1898.

*William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

GARRY E. CULVER, A. M. 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

EDGAR R. CUMINGS, Ph. D., Bloomington, Ind.; Assistant Professor of Geology. Indiana University. August, 1901.

*HENRY P. CUSHING, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

REGINALD A. DALY, Ph. D., Ottawa, Canada; Geologist for Canada on International Boundary Commission. December, 1905.

*NELSON H. DARTON, United States Geological Survey, Washington, D. C.

*WILLIAM M. DAVIS, S. B., M. E., Cambridge, Mass.; Sturgis-Hooper Professor of Geology in Harvard University.

DAVID T. DAY, Ph. D., U. S. Geol. Survey, Washington, D. C. August, 1891.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; No. 80 Rua Visconde do Rio Branco. December, 1890.

*JOSEPH S. DILLER, B. S., U. S. Geological Survey, Washington, D. C.

EDWARD V. D'INVILLIERS, E. M., 506 Walnut St., Philadelphia, Pa. Dec., 1888.

RICHARD E. DODGE, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

NOAH FIELDS DRAKE, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

CHARLES R. DRYER, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

*EDWIN T. DUMBLE, 1306 Main St., Houston, Texas.

ARTHUR S. EAKLE, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

CHARLES R. EASTMAN, A. M., Ph. D., Cambridge, Mass.; In Charge of Vetebrate Paleontology, Museum of Comparative Zoology, Harvard University. December, 1895.

EDWIN C. ECKEL, B. S., C. E., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

ARTHUR H. ELFTMAN, Ph. D., 706 Globe Building, Minneapolis, Minn. December, 1898.

*BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor in Amherst College.

*SAMUEL F. EMMONS, A. M., E. M., U. S. Geological Survey, Washington, D. C.

JOHN EYERMAN, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

HAROLD W. FAIRBANKS, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

*HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. FALES, Danville, Ky.; Professor in Centre College. December, 1888.

OLIVER C. FARRINGTON, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

NEVIN M. FENNEMAN, Ph. D., Madison, Wis.; Professor of Geology, University of Wisconsin. December, 1904.

AUGUST F. FOERSTE, Ph. D., 417 Grand Ave., Dayton, Ohio; Teacher of Sciences. December, 1899.

WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

*PERSIFOR FRAZER, D. ès-Sc. Nat., 1082 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Horticultural Society of Pennsylvania.

*HOMER T. FULLER, Ph. D., Fredonia, N. Y.

MYRON LESLIE FULLER, S. B., U. S. Geological Survey, Washington, D. C. December, 1898.

HENRY STEWART GANE, Ph. D., Santa Barbara, Cal. December, 1896.

HENRY GANNETT, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

*GROVE K. GILBERT, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

ADAM CAPEN GILL, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

L. C. GLENN, Ph. D., Nashville, Tenn.; Professor of Geology in Vanderbilt University. June, 1900.

CHARLES H. GORDON, Ph. D., 5516 14th Ave., N. E., Seattle, Wash., Assistant Geologist, U. S. Geological Survey. August, 1893.

CHARLES NEWTON GOULD, A. M., Norman, Okla.; Professor of Geology, University of Oklahoma. December, 1904.

AMADEUS W. GRABAU, S. M., S. D., Columbia University, New York city; Professor of Paleontology. December, 1898.

ULYSSES SHERMAN GRANT, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

HERBERT E. GREGORY, Ph. D., New Haven, Conn.; Assitant Professor of Physiography, Yale University. August, 1901.

GEORGE P. GRIMSLEY, Ph. D., Morgantown, W. Va.; Assistant State Geologist, Geological Survey of West Virginia. August, 1895.

LEON S. GRISWOLD, A. B., Rolla, Missouri. August, 1902.

FREDERIC P. GULLIVER, Ph. D., Norwichtown, Conn. August, 1895.

ARNOLD HAGUE, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

*CHRISTOPHER W. HALL, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

GILBERT D. HARRIS, Ph. B., Ithaca, N. Y.; Assistant Professor of Paleontology and Stratigraphic Geology, Cornell University. December, 1903.

JOHN BURCHMORE HARRISON, M. A., F. I. C., F. G. S., Georgetown, British Guiana; Government Geologist. June, 1902.

JOHN B. HASTINGS, M. E., 1480 High St., Denver, Colo. May, 1889.

*ERASMUS HAWORTH, Ph. D., Lawrence, Kans.; Professor of Geology, University of Kansas.

C. WILLARD HAYES, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*ANGELO HEILPRIN, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

RICHARD R. HICE, B. S., Beaver, Pa. December, 1903.

*EUGENE W. HILGARD, Ph. D., LL. D.; Berkeley, Cal.; Professor of Agriculture in University of California.

FRANK A. HILL, Roanoke, Va. May, 1889.

*ROBERT T. HILL, B. S., Trinity Building, New York City.

RICHARD C. HILLS, Mining Engineer, Denver, Colo. August, 1894.

*CHARLES H. HITCHCOCK, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

WILLIAM HERBERT HOBBS, Ph. D., Ann Arbor, Mich.; Professor of Geology, University of Michigan; Assistant Geologist, U. S. Geological Survey. August, 1891.

*LEVI HOLBROOK, A. M., P. O. Box 536, New York city.

ARTHUR HOLLICK, Ph. B., N. Y. Botanical Garden, Bronx Park, New York; Instructor in Geology, Columbia University. August, 1893.

*JOSEPH A. HOLMES, 6017 Cabanne Ave., Saint Louis, Mo.; State Geologist of North Carolina; In charge of investigation of fuels and structural materials, U. S. Geological Survey.

THOMAS C. HOPKINS, Ph. D., Syracuse, N. Y.; Professor of Geology, Syracuse University. December, 1894.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Associate Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

Ernest Howe, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

John D. Irving, Ph. D., South Bethlehem, Pa.; Professor of Geology, Lehigh University. December, 1905.

A. Wendell Jackson, Ph. B., 432 Saint Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Assistant Professor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Mark S. W. Jefferson, A. M., Ypsilanti, Mich.; Professor of Geography, Michigan State Normal School. December, 1904.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, Ph. D., Socorro, N. Mex. August, 1890.

Edward M. Kindle, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

Edward Henry Kraus, Ph. D., Ann Arbor, Mich.; Junior Professor of Mineralogy, University of Michigan. June, 1902.

Henry B. Kummel, Ph. D., Trenton, N. J.; State Geologist. December, 1895.

*George F. Kunz, A. M. (Hon.), Ph. D. (Hon.), care of Tiffany & Co., 15 Union Square, New York city.

George Edgar Ladd, Ph. D., Rolla, Mo.; Director School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Alfred C. Lane, Ph. D., Lansing, Mich.; State Geologist of Michigan. December, 1889.

Daniel W. Langton, Ph. D., Fuller Building, New York city; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Professor of Geology and Mineralogy in the University of California. May, 1889.

Willis Thomas Lee, M. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

Charles K. Leith, Ph. D., Madison, Wis.; Professor of Geology, University of Wisconsin; Assistant Geologist, U. S. Geological Survey. December, 1902.

Arthur G. Leonard, Ph. D., Grand Forks, N. Dak.; Professor of Geology and State Geologist, State University of North Dakota. December, 1901.

Frank Leverett, B. S., Ann Arbor, Mich.; Geologist, U. S. Geological Survey. August, 1890.

William Libbey, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

Waldemar Lindgren, M. E., U. S. Geological Survey, Washington, D. C. August, 1890.

George Davis Louderback, Ph. D., California, Berkeley, Cal. June, 1902.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. S., Ottawa, Canada; Geologist, Geological Survey of Canada. December, 1905.

Thomas H. Macbride, A. M., Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Hiram Deyer McCaskey, B. S., South Bethlehem, Pa. December, 1904.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August 1891.

*W J McGee, LL. D., Director Public Museum, Saint Louis, Mo.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Curtis F. Marbut, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

Vernon F. Marsters, A. M., Bloomington, Ind.; Professor of Geology in Indiana State University. August, 1892.

George Curtis Martin, Ph. D., Washington, D. C.; U. S. Geological Survey. June, 1902.

Edward B. Mathews, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

William D. Matthew, Ph. D., New York City; Associate Curator in Vertebrate Paleontology, American Museum of Natural History. December, 1903.

P. H. Mell, M. E., Ph. D., Clemson College, S. C.; President of Clemson College. December, 1888.

Warren C. Mendenhall, B. S., 1108 Braly Building, Los Angeles, Cal.; Geologist U. S. Geological Survey. June, 1902.

John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

*Frederick J. H. Merrill, Ph. D., New Rochelle, N. Y.; Consulting Geologist.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

Arthur M. Miller, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

Benjamin L. Miller, Ph. D., Bryn Mawr, Pa.; Associate in Geology, Bryn Mawr College. December, 1904.

Willet G. Miller, M. A., Toronto, Canada; Provincial Geologist of Ontario. December, 1902.

Henry Montgomery, Ph. D., Toronto, Canada; Curator of Museum University of Toronto. December, 1904.

*Frank L. Nason, A. B., West Haven, Conn.

John F. Newsom, Ph. D., Stanford University, Cal.; Associate Professor of Mining. December, 1899.

William H. Niles, Ph. B., M. A., Boston, Mass.; Professor, Emeritus, of Geology, Massachusetts Institute of Technology; Professor of Geology, Wellesley College. August, 1891.

William H. Norton, M. A., Mount Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Lexington, Ky.; Professor of Mining, State College of Kentucky. August, 1894.

Cleophas C. O'Harra, Ph. D., Rapid City, S. Dak.; Professor of Mineralogy and Geology, South Dakota School of Mines. December, 1904.

EZEQUIEL ORDONEZ, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

*AMOS O. OSBORN, Waterville, Oneida county, N. Y.

HENRY F. OSBORN, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1894.

CHARLES PALACHE, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.

*HORACE B. PATTON, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

FREDERICK B. PECK, Ph. D., Easton, Pa.; Professor of Geology and Mineralogy, Lafayette College. August, 1901.

RICHARD A. F. PENROSE, JR., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

GEORGE H. PERKINS, Ph. D., Burlington, Vt.; State Geologist. Professor of Geology, University of Vermont. June, 1902.

JOSEPH H. PERRY, 276 Highland St., Worcester, Mass. December, 1888.

LOUIS V. PIRSSON, Ph. D., New Haven, Conn.; Professor of Physical Geology, Sheffield Scientific School of Yale University. August, 1894.

*JULIUS POHLMAN, M. D., University of Buffalo, Buffalo, N. Y.

JOHN BONSALL PORTER, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

JOSEPH HYDE PRATT, Ph. D., Chapel Hill, N. C.; Mineralogist, North Carolina Geological Survey. December, 1898.

*CHARLES S. PROSSER, M. S., Columbus, Ohio; Professor of Geology in Ohio State University.

*RAPHAEL PUMPELLY, U. S. Geological Survey, Dublin, N. H.

ALBERT HOMER PURDUE, B. A., Fayetteville, Ark.; Professor of Geology, University of Arkansas. December, 1904.

FREDERICK LESLIE RANSOME, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

HARRY FIELDING REID, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

WILLIAM NORTH RICE, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

CHARLES H. RICHARDSON, Ph. D., Syracuse, N. Y.; Assistant Professor of Geology and Mineralogy, Syracuse University. December, 1899.

HEINRICH RIES, Ph. D., Cornell University, Ithaca, N. Y.; Assistant Professor in Economic Geology. December, 1893.

RUDOLPH RUEDEMANN, Ph. D., Albany, N. Y.; Assistant State Paleontologist. December, 1905.

*JAMES M. SAFFORD, M. D., LL. D., Dallas, Texas.

ORESTES H. ST. JOHN, Raton, N. Mex. May, 1889.

*ROLLIN D. SALISBURY, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

FREDERICK W. SARDESON, Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

FRANK C. SCHRADER, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

CHARLES SCHUCHERT, New Haven, Conn.; Curator, Geological Department, Yale University. August, 1895.

WILLIAM B. SCOTT, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

ARTHUR EDMUND SEAMAN, B. S., Houghton, Mich.; Professor of Mineralogy and Geology, Michigan College of Mines. December, 1904.

HENRY M. SEELY, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1899.

ELIAS H. SELLARDS, Ph. D., Gainesville, Fla.; Professor of Geology, etc., in University of Florida. December, 1905.

GEORGE BURBANK SHATTUCK, Ph. D., Poughkeepsie, N. Y.; Professor of Geology in Vassar College. August, 1899.

SOLON SHEDD, A. B., Pullman, Wash.; Professor of Geology and Mineralogy, Washington Agricultural College. December, 1904.

EDWARD M. SHEPARD, Sc. D., Springfield, Mo.; Professor of Geology, Drury College. August, 1901.

WILL H. SHERZER, M. S., Ysilanti, Mich.; Professor in State Normal School. December, 1890.

BOHUMIL SHIMEK, C. E., M. S., Iowa City, Iowa; Professor of Physiological Botany, University of Iowa. December, 1904.

*FREDERICK W. SIMONDS, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

*EUGENE A. SMITH, Ph. D., University, Tuscaloosa county, Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

FRANK CLEMES SMITH, E. M., Richland Center, Wis.; Mining Engineer. December, 1898.

GEORGE OTIS SMITH, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

WILLIAM S. T. SMITH, Ph. D., 749 N. Lake St., Reno, Nev.; Associate Professor of Geology and Mineralogy, University of Nevada. June, 1902.

*JOHN C. SMOCK, Ph. D., Trenton, N. J.; State Geologist.

CHARLES H. SMYTH, JR., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

HENRY L. SMYTH, A. B., Cambridge, Mass.; Professor of Mining and Metallurgy in Harvard University. August, 1894.

ARTHUR COE SPENCER, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

*J. W. SPENCER, Ph. D., 2019 Hillyer Place, Washington, D. C.

JOSIAH E. SPURR, A. B., A. M., U. S. Geological Survey, Washington, D. C. December, 1894.

JOSEPH STANLEY-BROWN, Cold Spring Harbor, Long Island, N. Y. August, 1892.

TIMOTHY WILLIAM STANTON, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

*JOHN J. STEVENSON, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

WILLIAM J. SUTTON, B. S., E. M., Victoria, B. C.; Geologist to E. and N. Railway Co. August, 1901.

JOSEPH A. TAFF, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

JAMES E. TALMAGE, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

RALPH S. TARR, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

FRANK B. TAYLOR, Fort Wayne, Ind. December, 1895.

WILLIAM G. TIGHT, M. S., Albuquerque, N. Mex.; President and Professor of Geology, University of New Mexico. August, 1897.

*JAMES E. TODD, A. M., Vermilion, S. Dak.; Assistant Geologist, U. S. Geological Survey

*HENRY W. TURNER, B. S., 508 California St., San Francisco, Cal.

JOSEPH B. TYRRELL, M. A., B. Sc., 87 Binscarth Road, Toronto, Canada. May, 1889.

JOHAN A. UDDEN, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

EDWARD O. ULRICH, D. Sc., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*WARREN UPHAM, A. M., Librarian Minnesota Historical Society, Saint Paul, Minn.

*CHARLES R. VAN HISE, M. S., Ph. D., Madison, Wis.; President University of Wisconsin; Geologist, U. S. Geological Survey.

FRANK ROBERTSON VAN HORN, Ph. D., Cleveland, Ohio; Professor of Geology and Mineralogy, Case School of Applied Science. December, 1898.

GILBERT VANINGEN, Princeton, N. J.; Curator of Invertebrate Paleontology and Assistant in Geology, Princeton University. December, 1904.

THOMAS WAYLAND VAUGHN, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

*ANTHONY W. VODGES, San Diego, Cal.; Captain Fifth Artillery, U. S. Army.

*MARSHMAN E. WADSWORTH, Ph. D., State College, Pa.; Professor of Mining and Geology, Pennsylvania State College.

*CHARLES D. WALCOTT, LL. D., Washington, D. C.; Secretary Smithsonian Institution.

THOMAS L. WALKER, Ph. D., Toronto, Canada; Professor of Mineralogy and Petrograhpy, University of Toronto. December, 1903.

CHARLES H. WARREN, Ph. D., Boston, Mass.; Instructor in Geology, Massachusetts Institute of Technology. December, 1901.

HENRY STEPHENS WASHINGTON, Ph. D., Locust, Monmouth Co., N. J.; August, 1896.

THOMAS L. WATSON, Ph. D., Blacksburg, Va.; Professor of Geology in Virginia Polytechnic Institute. June, 1900.

WALTER H. WEED, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

FRED. BOUGHTON WEEKS, Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

SAMUEL WEIDMAN, Ph. D., Madison, Wis.; Geologist, Wisconsin Geological and Natural History Survey. December, 1903.

STUART WELLER, B. S., Chicago, Ill.; Instructor in University of Chicago. June, 1900.

LEWIS G. WESTGATE, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

THOMAS C. WESTON, 591 Saint John St., Quebec, Canada. August, 1893.

DAVID WHITE, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

*ISRAEL C. WHITE, Ph. B., Morgantown, W. Va.

*ROBERT P. WHITFIELD, Ph. D., American Museum of Natural History, 78th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

FRANK A. WILDER, Ph. D., Iowa City, Iowa; Professor of Economic Geology, University of Iowa; State Geologist. December, 1905.

*EDWARD H. WILLIAMS, JR., A. C., E. M., Andover, Mass.

*HENRY S. WILLIAMS, Ph. D., Ithaca, N. Y.; Professor of Geology and Head of Geological Department, Cornell University.

IRA A. WILLIAMS, M. Sc., Ames, Iowa; Teacher Iowa State College. December, 1905.

BAILEY WILLIS, U. S. Geological Survey, Washington, D. C. December, 1889.

SAMUEL W. WILLISTON, Ph. D., M. D., Chicago, Ill.; Professor of Paleontology, University of Chicago. December, 1889.

ARTHUR B. WILLMOTT, M. A., Sault Ste. Marie, Ontario, Canada. December, 1899.

ALFRED W. G. WILSON, Ph. D., 197 Park ave., Montreal, Ont., Canada; Mining Geologist. June, 1902.

ALEXANDER N. WINCHELL, Doct. U. Paris, Butte, Mont.; Professor of Geology and Mineralogy, Montana State School of Mines. August, 1901.

*HORACE VAUGHN WINCHELL, St. Paul, Minn.; Geologist for the Great Northern Railway Company.

*NEWTON H. WINCHELL, A. M., Minneapolis, Minn.; editor *American Geologist.*

*ARTHUR WINSLOW, B. S., 84 State St., Boston, Mass.

JOHN E. WOLFF, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

JOSEPH E. WOODMAN, S. D., Halifax, N. S.; Assistant Professor of Geology and Mineralogy, Dalhousie University. December, 1905.

ROBERT S. WOODWARD, C. E., Washington, D. C.; President of the Carnegie Institution of Washington. May, 1889.

JAY B. WOODWORTH, B. S., 24 Langdon St., Cambridge, Mass.; Assistant Professor of Geology, Harvard University. December, 1895.

FREDERIC E. WRIGHT, Ph. D., U. S. Geological Survey, Washington, D. C. December, 1903.

*G. FREDERICK WRIGHT, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary

WILLIAM S. YEATES, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894

GEORGE A. YOUNG, Ph. D., Ottawa, Canada; Geologist, Geological Survey of Canada. December, 1905.

FELLOWS DECEASED.

*Indicates Original Fellow (see article III of Constitution)

*CHARLES A. ASHBURNER, M. S., C. E. Died December 24, 1889.

CHARLES E. BEECHER, Ph. D. Died February 14, 1904.

AMOS BOWMAN. Died June 18, 1894.

*J. H. CHAPIN, Ph. D. Died March 14, 1892.

*EDWARD W. CLAYPOLE, D. Sc. Died August 17, 1901.

GEORGE H. COOK, Ph. D., LL. D. Died September 22, 1889.

*EDWARD D. COPE, Ph. D. Died April 12, 1897.

ANTONIO DEL CASTILLO. Died October 28, 1895.

*JAMES D. DANA, LL. D. Died April 14, 1895.

GEORGE M. DAWSON, D. Sc. Died March 2, 1901.

Sir J. WILLIAM DAWSON, LL. D. Died November 19, 1899.

*WILLIAM B. DWIGHT, Ph. B. Died August 29, 1906.

*GEORGE H. ELDRIDGE, A. B. Died June 29, 1905.

*ALBERT E. FOOTE. Died October 10, 1895.

N. J. GIROUX, C. E. Died November 30, 1890.

*JAMES HALL, LL. D. Died August 7, 1898.

JOHN B. HATCHER, Ph. B. Died July 3, 1904.

*ROBERT HAY. Died December 14, 1895.

DAVID HONEYMAN, D. C. L. Died October 17, 1889.

THOMAS STERRY HUNT, D. Sc., LL. D. Died February 12, 1892.
*ALPHEUS HYATT, B. S. Died January 15, 1902.
*JOSEPH F. JAMES, M. S. Died March 29, 1897.
WILBUR C. KNIGHT, B. S., A. M. Died July 28, 1903.
RALPH D. LACOE. Died February 5, 1901.
*JOSEPH LE CONTE, M. D., LL. D. Died July 6, 1901.
*J. PETER LESLEY, LL. D. Died June 2, 1903.
HENRY MCCALLEY, A. M., C. E. Died November 20, 1904.
OLIVER MARGY, LL. D. Died March 19, 1899.
OTHNIEL C. MARSH, Ph. D., LL. D. Died March 18, 1899.
JAMES E. MILLS, B. S. Died July 25, 1901.
*HENRY B. NASON, M. D., Ph. D., LL. D. Died January 17, 1895.
*PETER NEFF, M. A. Died May 11, 1903.
*JOHN S. NEWBERRY, M. D., LL.D. Died December 7, 1892.
*EDWARD ORTON, Ph. D., LL. D. Died October 16, 1899.
*RICHARD OWEN, LL. D. Died March 24, 1890.
SAMUEL L. PENFIELD. Died August 14, 1906.
*FRANKLIN PLATT. Died July 24, 1900.
*WILLIAM H. PETTEE, A. M. Died May 26, 1904.
*JOHN WESLEY POWELL, LL. D. Died September 23, 1902.
*ISRAEL C. RUSSELL, LL. D. Died May 1, 1906.
*CHARLES SCHAEFFER, M. D. Died November 23, 1903.
*NATHANIEL S. SHALER, LL. D. Died April 10, 1906.
CHARLES WACHSMUTH. Died February 7, 1896.
THEODORE G. WHITE, Ph. D. Died July 7, 1901.
*GEORGE H. WILLIAMS, Ph. D. Died July 12, 1894.
*J. FRANCIS WILLIAMS, Ph. D. Died November 9, 1891.
*ALEXANDER WINCHELL, LL. D. Died February 19, 1891.
ALBERT A. WRIGHT, Ph. D. Died April 2, 1905.

Summary

Original Fellows	62
Elected Fellows	221
Membership	283
Deceased Fellows	48

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